USACERL Technical Report 95/41
September 1995

US Army Corps
of Engineers
Construction Engineering
Research Laboratories

Ten-Year Summary and Final Report of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units

by
Robert D. Neathammer

To determine if manufactured/factory-built family housing is more cost-effective in providing housing than conventional construction, Congress directed that a test of construction methods be conducted. In 1982, Congress authorized the construction of 200 units of manufactured/factory-built housing at Fort Irwin, CA, and concurrently, 144 units of conventionally built units.

Congress directed the Department of Defense (DOD) to conduct a fair and reliable study comparing the operation and maintenance (O&M) costs of manufactured housing to those of conventional housing. DOD reported to Congressional committees on the conditions and parameters under which this test would be conducted and the results of the test after the housing had been in use for 5 years.

The Assistant Secretary of the Army for Installations, Logistics, and Environment requested that the study be extended beyond the 5 years. This report compares 10 years of O&M costs.

Through 10 years of occupancy, maintenance costs for the manufactured housing were significantly higher than for the conventionally built housing, with defective water piping a major problem.

Approved for public release; distribution is unlimited.

USER EVALUATION OF REPORT

REFERENCE: USACERL Technical Report 95/41, *Ten-Year Summary and Final Report of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*

Please take a few minutes to answer the questions below, tear out this sheet, and return it to USACERL. As user of this report, your customer comments will provide USACERL with information essential for improving future reports.

1. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which report will be used.)

____

____

____

2. How, specifically, is the report being used? (Information source, design data or procedure, management procedure, source of ideas, etc.)

____

____

3. Has the information in this report led to any quantitative savings as far as manhours/contract dollars saved, operating costs avoided, efficiencies achieved, etc.? If so, please elaborate.

____

____

4. What is your evaluation of this report in the following areas?

a. Presentation: ______________________________

b. Completeness: ______________________________

c. Easy to Understand: ______________________________

d. Easy to Implement: ______________________________

e. Adequate Reference Material: ______________________________

f. Relates to Area of Interest: ______________________________

g. Did the report meet your expectations? ______________________________

h. Does the report raise unanswered questions? ______________________________

i. General Comments. (Indicate what you think should be changed to make this report and future reports of this type more responsive to your needs, more usable, improve readability, etc.)

____

____

____

____

____

____

5. If you would like to be contacted by the personnel who prepared this report to raise specific questions or discuss the topic, please fill in the following information.

Name: ______________________

Telephone Number: ______________________

Organization Address: ______________________

____

____

6. Please mail the completed form to:

Department of the Army
CONSTRUCTION ENGINEERING RESEARCH LABORATORIES
ATTN: CECER-TR-I
P.O. Box 9005
Champaign, IL 61826-9005

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1995	Final

4. TITLE AND SUBTITLE
Ten-Year Summary and Final Report of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units

5. FUNDING NUMBERS
MIPR
SFIM-IS 5CCER00014

6. AUTHOR(S)
Robert D. Neathammer

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Construction Engineering Research Laboratories (USACERL)
P.O. Box 9005
Champaign, IL 61826-9005

8. PERFORMING ORGANIZATION REPORT NUMBER
TR 95/41

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Headquarters, Department of the Army
ATTN: DAIM-FDH-F
600 Army Pentagon
Washington, DC 20310-0600

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
To determine if manufactured/factory-built family housing is more cost-effective in providing housing than conventional construction, Congress directed that a test of construction methods be conducted. In 1982, Congress authorized the construction of 200 units of manufactured/factory-built housing at Fort Irwin, CA, and concurrently, 144 units of conventionally built units.

Congress directed the Department of Defense (DOD) to conduct a fair and reliable study comparing the operation and maintenance (O&M) costs of manufactured housing to those of conventional housing. DOD reported to Congressional committees on the conditions and parameters under which this test would be conducted and the results of the test after the housing had been in use for 5 years.

The Assistant Secretary of the Army for Installations, Logistics, and Environment requested that the study be extended beyond the 5 years. This report compares 10 years of O&M costs.

Through 10 years of occupancy, maintenance costs for the manufactured housing were significantly higher than for the conventionally built housing, with defective water piping a major problem.

14. SUBJECT TERMS
Fort Irwin, CA
family housing
industrialized building

15. NUMBER OF PAGES
64

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18
298-102

FOREWORD

This research was conducted for the U.S. Army Center for Public Works (USACPW), and the Assistant Chief of Staff for Installation Management (ACS(IM)), Directorate of Facilities and Housing (DAIM-FDH-F), under the following Intra Agency Orders (IAOs) from Fort Irwin and Headquarters, U.S. Army Forces Command (FORSCOM): FHAA022-83, dated August 1983; R039-84, dated May 1984; S040-85, dated January 1985; T016-86, dated November 1986; CERL-87, dated December 1987; CERL-88, dated June 1988; CERL-89, dated 2 March 1989; Headquarters, U.S. Army Corps of Engineers (HQUSACE) FAD 90-080031, dated September 1990; HQUSACE FAD 91-080025, dated September 1991; HQUSACE FAD 92-080020, dated 10 August 1992; HQUSACE FAD 93-080024, dated 17 September 1993; HQUSACE FAD 940814461, dated 27 September 1994; and SFIM-IS MIPR 5CCER00014, dated 5 December 1994. The USACPW technical monitor was Alex Houtzager (DAIM-FDH-F). Other technical advisors from USACPW were Robert Lubbert and Joe Hovell. Coordination and advice from FORSCOM were provided by Bill Mann, FCEN-RDM. The Fort Irwin advisors were Tom Cragg, Walt Perry, Rene Quinones, and Apolonia Garcia.

The work was performed by the Maintenance Management and Preservation Division (FL-P) of the Facilities Technology Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL). The principal investigator was Robert Neathammer, CECER-FL-P. Simon Kim is Chief, CECER-FL-P. Donald F. Fournier, Jr. is acting Operations Chief, CECER-FL, and Alvin Smith is acting Chief, CECER-FL. Data validation entry and analysis were performed by Robert F. Doerr Jr., Gwendolyn Karzon, and Jeffrey Schmidt, CECER-FL-P. Data collection efforts by Dyncorp were coordinated by Dee Foley and Donald Hamblett.

COL James T. Scott is Commander and Acting Director of USACERL, and Dr. Michael J. O'Connor is Technical Director.

CONTENTS

FIGURES

TABLES

TEN-YEAR SUMMARY AND FINAL REPORT OF FORT IRWIN, CA, FAMILY HOUSING COMPARISON TEST: OPERATION AND MAINTENANCE COSTS OF MANUFACTURED vs. CONVENTIONALLY BUILT UNITS

1 INTRODUCTION

Background

Congress believed that use of manufactured (factory built) military housing, rather than conventionally built units, would result in lower overall costs and provide durable housing that meets contemporary housing standards. To verify this belief, Congress directed the Department of Defense (DOD) to construct 200 units of manufactured housing at Fort Irwin, CA, and compare them with similarly designed, conventionally built housing.[1] DOD was also directed to perform a study comparing the operation and maintenance (O&M) costs of the two types of construction over a 5-year period. The conditions and parameters for this test were submitted to Congress.

Results of the 5-year study showed no difference in O&M costs between the two types of construction. However, the Assistant Secretary of the Army for Installations, Logistics, and Environment, and managers at the Office of the Assistant Chief of Staff for Installation Management (OACS(IM)), U.S. Army Center for Public Works (USACPW), and the U.S. Army Construction Engineering Research Laboratories (USACERL) thought 5 years was too short a time for valid comparisons of O&M costs. Thus, USACERL was asked to continue collecting and analyzing data and to report results at the end of each year for an additional 5 years in order to identify broad trends. Then a final report based on 10 years of data was to be provided.

The manufactured units met Federal Manufactured Housing Construction and Safety Standards (FMHCSS); however, upgrades in certain criteria were specified to bring the units into conformance with DOD standards. These areas of concern included net usable floor space, energy efficiency, fire and life safety, and durability of certain materials and components. The study compared the impact of the modified FMHCSS versus standard DOD criteria, except for the essential criteria listed in the previous sentence.

The study began when the housing units were first occupied; initial occupancy of some units started in February 1983. The study compares 200 two-bedroom manufactured units to 144 two-bedroom, conventionally built units. The two types of units were similar in floor area, floor plans, and materials used.

The data collected address O&M costs for both types of housing. The study identifies not only the differences, if any, in O&M costs, but also the reasons for the differences and their importance for future construction criteria and construction methods.

Objective

This report summarizes the O&M costs for both conventionally built and manufactured housing from construction through the first 10 years of occupancy.

[1] Report No. 97-44, *Military Construction Authorization Act* (House of Representatives Committee on Armed Services, 1982), pp 8-9.

Approach

The first step was to develop uniform data collection and data analysis procedures. The cost comparisons and analyses for this study were established in USACERL Special Report (SR) P-140.[2] Data were collected throughout the study and summarized/reported yearly. First-year data were reported in USACERL Interim Report (IR) P-85/14;[3] second-year data in USACERL IR P-86/06;[4] third-year data in USACERL IR P-87/10;[5] fourth-year data in USACERL IR P-88/09;[6] 4 1/2-year data in USACERL IR P-89/14;[7] fifth-year data in USACERL TR P-90/11;[8] sixth-year data in USACERL TR P-91/37;[9] seventh-year date in USACERL TR FF-92/08;[10] eighth-year data in USACERL TR FF-93/09;[11] and ninth-year data in USACERL TR FF-94/21.[12]

Individuals were assigned to quarters with no distinction between the two types of units. The units all have the same floor area and were occupied by essentially the same ranks/ages of sponsors; assignment of families was not biased by the type of construction.

Scope

Study costs were limited to the buildings themselves, as the intent of the study was to compare O&M costs of the two types of construction. Thus, sidewalks, driveways, streets, lawns, playgrounds, and utility lines outside the buildings were not included. Also, the replacement costs of refrigerators, kitchen stoves, and utility meters were excluded. (Because of these exclusions, the unit cost data in this report *is not comparable* to standard unit cost data reported for family housing in many Army financial reports, which normally includes costs such as streets and utility lines.)

---

2 M.J. O'Connor, *Fort Irwin Housing Comparison Test*, Special Report (SR) P-140/ADA130349 (USACERL, 1983).

3 R.D. Neathammer, *Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, Interim Report (IR) P-85/14/ADA159740 (USACERL, 1985).

4 R.D. Neathammer, *Two-Year Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, IR P-86/06/ADA175995 (USACERL, 1986).

5 R.D. Neathammer, *Three-Year Summary of Fort Irwin, CA, Family Housing Comparison Test; Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, IR P-87/10/ ADA180001 (USACERL, 1987).

6 R.D. Neathammer, *Four-Year Summary of Fort Irwin, CA, Family Housing Comparison Test; Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, IR P-88/09/ADA190017 (USACERL, 1988).

7 R.D. Neathammer, *May 1984 to September 1988 Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, IR P-89/14/ADA209421 (USACERL, 1989).

8 R.D. Neathammer, *Five-Year Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, TR P-90/11/ADA222176 (USACERL, 1990).

9 R.D Neathammer, *Six-Year Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenace Costs of Manufactured vs. Conventionally Built Units*, TR P-91/37/ADA237479 (USACERL, 1991).

10 R. D. Neathammer, *Seven-Year Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, TR FF-92/08/ADA256255 (USACERL, 1992).

11 R.D. Neathammer, *Eight-Year Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, TR FF-93/09/ADA273102 (USACERL, 1993).

12 R.D. Neathammer, *Nine-Year Summary of Fort Irwin, CA, Family Housing Comparison Test, Operation and Maintenance Costs of Manufactured vs.Conventionally Built Units*, TR FF-94/21/ADA280407 (USACERL, 1994).

2 REVIEW OF TEST PLAN

USACERL SR P-140 detailed the cost data collection plan and analysis methods. Four basic questions on costs were:

1. Did the average annual O&M costs differ significantly?

2. If different, where were they significantly different?

3. Why did the costs differ?

4. What criteria, design features, etc., need to be changed as a result?

Overall maintenance costs and utility costs were compared separately. If significant differences were found, then the causes of these differences were determined.

In addition to the overall cost comparison, the maintenance costs for major building components were compared. These comparisons provide more detail about where and why cost differences occur.

Occupant satisfaction with the overall apartments and each physical part of the unit was compared for the two types of construction after the first 5 years of occupancy and reported in USACERL P-90/11. When occupant satisfaction differed for a building component, that component was evaluated to determine the reason for the difference.

3 DESCRIPTION OF THE FAMILY HOUSING UNITS

Manufactured Housing Units (MHUs)

These 200 units consist of 50 two-story fourplexes (two units on each of the first and second floors). Net floor area is 950 sq ft/unit* and gross area averages 1160 sq ft/unit. These were constructed on perimeter footings with wood floors and crawl spaces. Each upper unit has a balcony-porch and each lower unit has a patio with privacy fencing. Figure 1 shows front and rear views of typical buildings. Each unit has a refrigerator, gas range, gas water heater, garbage disposal, dishwasher, central air conditioning, and gas-fired forced-air furnace (all provided by the contractor). Each unit has two bedrooms, a kitchen, living-dining area, one bathroom, a utility room, and a one-car garage. The garage was constructed on site.

A detailed description of the construction process including photographs and floor plans for the units is shown in Appendix A.

The notice to proceed date was 10 January 1983. Initial occupancy was:

61	units	Dec 83
7	units	Jan 84
64	units	Feb 84
57	units	Apr 84
9	units	May 84
2	units	Jun 84

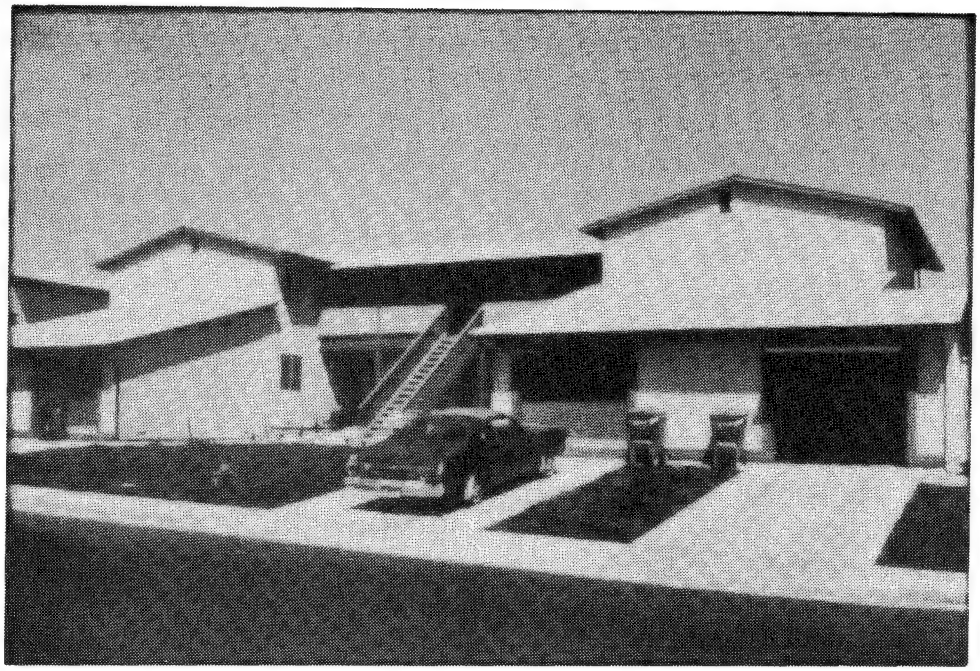
Conventionally Built Units (CBUs)

The 144 units consist of 13 sixplexes, 6 fiveplexes, and 9 fourplexes, all two-story buildings. Net floor area is 950 sq ft/unit and gross area averages 1120 sq ft/unit. These units were constructed on perimeter footings with building slab. Each unit has two bedrooms, a kitchen, living-dining area, one bathroom, utility room, either a fenced patio or balcony-porch (for upper unit), and a one-car garage. Figure 2 shows front and rear views of typical buildings. The fourplexes have two units on each level. There are two units on the second story in the five- and sixplexes with the additional unit(s) on the first level. The CBUs also have a refrigerator, gas range, gas water heater, garbage disposal, dishwasher, central air conditioning, and gas-fired forced-air furnace.

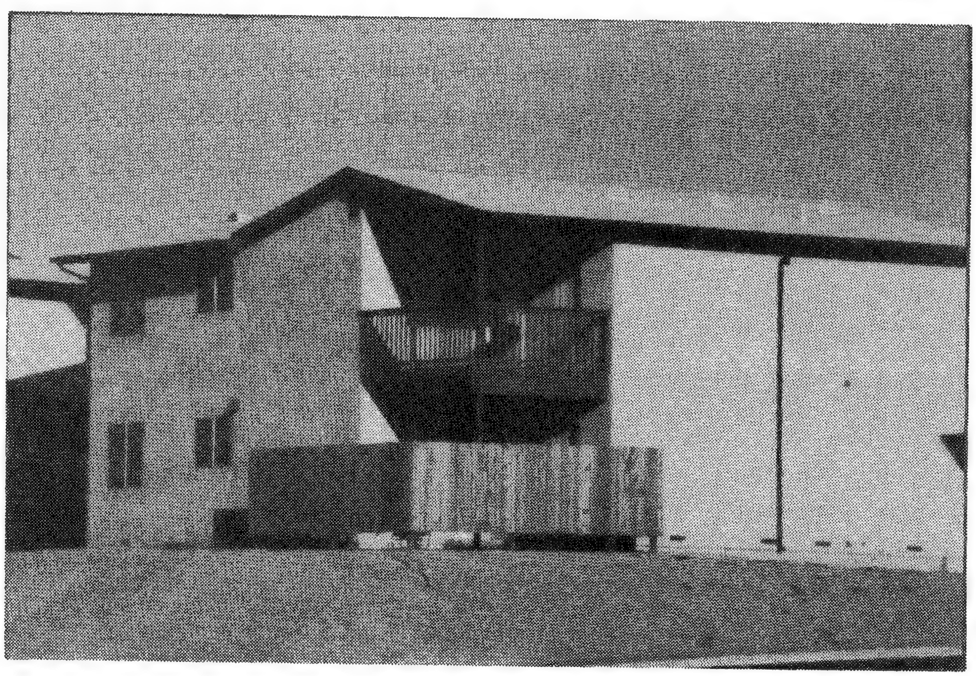
The notice to proceed date was 3 May 1982. Initial occupancy was:

8	units	Feb 83
28	units	Mar 83
38	units	Apr 83
31	units	May 83
23	units	Jun 83
14	units	Jul 83
2	units	Aug 83

* Metric conversions: 1 cu ft = 0.028 m^3; 1 sq ft = 0.093 m^2; °C = 0.55 x (°F-32).

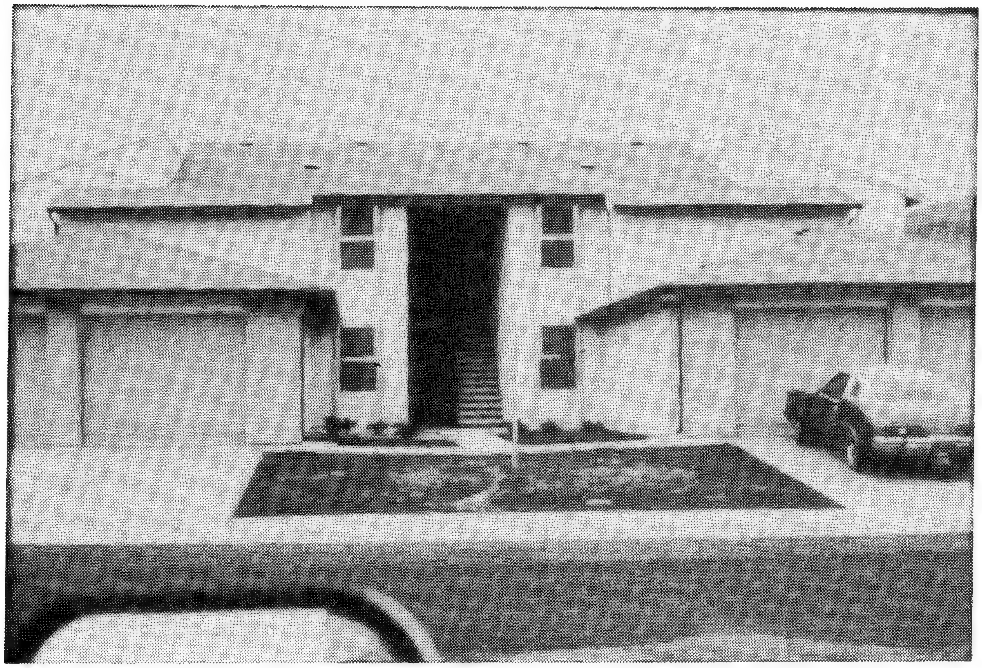


Front View - MHU

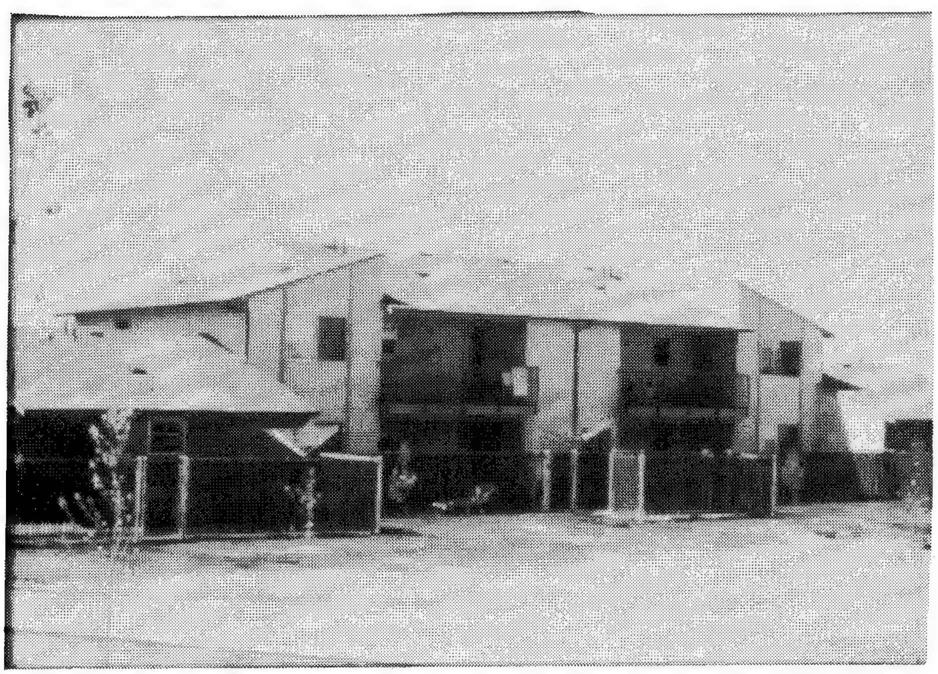


Rear View - MHU

Figure 1. Front and rear views of typical MHUs.



Front View - CBU



Rear View - CBU

Figure 2. Front and rear views of typical CBUs.

A detailed description of all units can be found in the Los Angeles District Office report.[13] The buildings were not specifically adapted to the desert environment but are typical Southern California design.

Costs

A clear-cut initial cost comparison of the two unit types was not possible. The 144 CBUs were part of a project of 254 units. The cost for this project was $51.83/sq ft. The 200 MHUs costs were $51.22/sq ft. However, the supervision and administration costs for the MHUs were based on the same 5 percent rate used for the CBUs. More labor was required since quality assurance inspection was required at the manufacturing plant as well as at the construction site. It was estimated that the additional labor would have raised the cost to $55/sq ft (no records were kept as these are all indirect costs).

General Comparison

Fort Irwin is located in a high desert environment. Annual rainfall averages 4 in. and temperatures often exceed 100 °F. The housing construction was not adapted to this climate but is representative of Southern California design. For example, rain gutters and downspouts were installed. As they began to fall off because of wind effects, they were not replaced.

The exterior finish of both unit types is stucco with some brick veneer on the garages. Exterior trim is painted wood. Asphalt shingles were used on both types, and gutters and downspouts were installed.

Interior walls are painted gypsum board. Floors on the second level are carpeted and are vinyl tile or vinyl sheet covering on the first floor.

Water piping is polybutylene in the MHUs and copper in the CBUs.

Windows are single pane in the MHUs and thermal pane in the CBUs.

First-story floors in MHUs are wood on crawl spaces and in CBUs are concrete slabs.

Grass was planted in the immediate yard area of the buildings, but not in play yard areas. Each first-floor unit has a concrete patio with a wooden privacy fence; each second-story unit has a wooden balcony-porch.

The Fort Irwin region averages 2,597 Heating Degree Days and 2,272 Cooling Degree Days annually.

[13] *Fort Irwin Family Housing Study—A Report on Manufactured/Factory-Built Housing and Site-Built Housing, Fort Irwin, CA* (U.S. Army Corps of Engineers, Los Angeles District, September 1984).

4 DATA COLLECTION PROCEDURES

Data were collected in enough detail that any differences found between the two types of construction could be explained. Appendix B lists the housing units and their identification numbers used in the data collection. Appendix C lists the building components and subcomponents. Each service order was coded to a component so the costs of components could be compared. A discussion of the data collected is included in USACERL SR P-140.

Data Collection

Discussions were held with representatives of the U. S. Army Engineering and Housing Support Center (USAEHSC) technical monitor; Forces Command Headquarters; Fort Irwin personnel; and the base operations contractor, Boeing Services International (BSI); to establish the best methods of collecting the data.

BSI was contracted to segregate all maintenance service orders for the test units and report the cost data to USACERL through the Fort Irwin Directorate of Engineering and Housing (DEH) monthly. BSI was also contracted to read gas and electric meters at the end of each month and report similarly.

A new contractor, Dynalectron (DynCorp), became the base operations contractor effective 1 October 1986 and has performed the same services.

Data Verification

USACERL verified the reported data several ways. For the first 5 years, each original work order (WO) document was checked against the reported data forwarded by the contractor. Discrepancies were resolved on verification visits to Fort Irwin. Additionally, the contractor set up separate accounting codes for the two groups of units and the total billed was compared to the total obtained from summing all the individual WO data. For years 6 through 10 the reported data was checked for obvious errors, which were resolved with the contractor. No detailed validation of each WO was made as the purpose of the continued study was to search for overall trends.

USACERL developed a computer program to compare gas and electricity meter readings. When apparently erroneous data occurred, the contractor was notified and corrections made if needed.

Data Analysis

Maintenance Costs

Maintenance costs were compared on a unit-month basis and yearly basis. The data were also summarized by building component to determine if one or more components for one of the types of units had large maintenance costs. If so, the reasons for these costs were determined to help define what criteria or design features should be reviewed/changed.

Cost differences could have been caused by material quality, installation, differences inherent to manufactured or conventional construction, and possible errors in specifications for the two projects.

Warranty work referred to the construction contractor was not included in the cost comparison since no cost data were available or applicable, as it was not a cost to the government. However, the cost of a service call to assess a problem was included.

Energy Consumption

Gas and electricity consumption were compared on a quarterly basis and a yearly basis. Since most of the MHUs were not completed until May 1984, prior energy consumption data for the CBUs was not used in comparisons. (Energy consumption comparisons are valid only for the same time frame because of varying weather conditions.)

5 WHOLE HOUSE ENERGY TESTS

Energy evaluations of sample units of each type of construction were performed immediately after construction was completed on each of the two groups of housing and again after 5 years of occupancy. The objective was to determine if energy characteristics had changed over the 5-year period. Three whole-house energy tests were performed. Appendixes D and E give details of the tests for the CBUs and MHUs, respectively.

House Tightness

The number of air changes per hour were measured with the following results:

	Immediately After Construction			After 5 Years		
Type	**No. Units**	**Average Air Change Per Hour**	**Standard Deviation (%)**	**No. Units**	**Average Air Change Per Hour**	**Standard Deviation (%)**
CBU	15	13.0	1.06	15	12.1	1.70
MHU	12	10.9	2.67	14	9.7	1.60

A statistically significant difference existed between the two types of construction for both the initial and 5-year tests, the MHUs being more airtight on the average. Neither type of unit changed significantly over the 5 years. These results indicate that the MHUs should have had less air infiltration/leakage.

Furnace Efficiency

The furnace efficiency results were as follows:

	Immediately After Construction			After 5 Years		
Type	**No. Units**	**Average Efficiency % Per Hour**	**Standard Deviation (%)**	**No. Units**	**Average Efficiency% Per Hour**	**Standard Deviation (%)**
CBU	13	66.2	6.24	14	64.2	12.2
MHU	16	79.3	3.36	15	77.3	2.84

The furnace efficiencies of the MHUs were significantly higher than those of the CBU for both the initial and 5-year tests. Neither type of unit changed significantly over the 5 years.

Wall Heat Transfer Characteristics

This parameter was not initially measured for the CBUs because of unfavorable weather during the testing period. This parameter was calculated for both types of construction using the designed wall construction.

Type	No. Units	Average Heat Loss (Btu/hr-°F)
CBU	16	1,072
MHU	15	1,220

Summary

The whole-house energy tests did not conclusively indicate which type of unit would use less energy for heating/cooling. The CBUs are more energy efficient considering only the wall heat loss test, but the MHUs perform better when tested for air tightness and furnace efficiency. Additionally, the CBUs are built on concrete slabs while the MHUs have a crawl space. Houses on concrete slabs use less energy than houses on crawl spaces. This has an impact on the first floor units' energy use.

Therefore, the tests are inconclusive in predicting which type of construction would use more energy for heating/cooling.

6 OPERATION AND MAINTENANCE (O&M) COSTS

O&M costs for each type of unit were compared over the first 10 years of occupancy. The test period for CBUs was 1 August 1983 through 31 July 1993; the test period for MHUs was 1 June 1984 through 31 May 1994.

Overall Costs

The total housing unit-months and maintenance costs for the first 10 years of occupancy are shown in Table 1. (Maintenance includes all types of repairs and "preventive maintenance" performed.)

Discussion

The MHUs cost about $105/ month more than the CBUs over the first 10 years of occupancy; the difference in cost per unit per year is $1,262. There were large increases in M&R costs in years 5, 7, 8, and 9. This is illustrated in Table 2, which shows M&R costs per year of occupancy.

Costs per unit have been increasing over time. Figure 3 shows the cumulative costs per unit per month for ages 15 to 120 months, illustrating this trend. The costs for the MHUs increased faster than for the CBUs. This trend can also be seen in Figure 4, which shows total costs per unit per year. Note: Figures 3 and 4 do not include the eaves cost in year 4 or the waterline replacement cost as these would distort the depiction of normal M&R cost growth.

Increased costs in years 5 and 8 were attributable partly to interior painting done in units vacated for the first time and in those which required painting on change of occupancy. Increased costs in years 8 and 9 for MHUs were due to water piping and roofing costs. Table 3 shows the painting costs per year of occupancy. Note the large increases for MHUs in year 5 and for CBUs in year 6. Painting costs for both increased again in year 9.

Table 4 lists the yearly costs excluding interior painting. This table shows that the MHUs' costs increased faster than the CBUs' through year 10. Both showed decreases in year 6 and increases in years 7, 8, and 9.

For comparison purposes, the M&R costs for all 1,808 permanent housing units (including the 144 CBU and 200 MHU test units) at Fort Irwin were:

FY94 - $3,488,000 or $1,929/unit
FY95 - $3,780,000 or $2,091/unit.

These costs cover all repairs, including those beyond the 5-ft line which the cost comparison did not cover. Thus, the study's year 10 costs of $1,047 for CBUs and $1,608 for MHUs are lower than the overall average cost for all units.

Table 1

Unit/Month Costs in First 10 Years' Occupancy

Type	No. Unit Months	Total Cost ($)	Cost/Unit/ Month ($)	Cost/Unit/ Year ($)
CBU	17,280	868,818	50	603
MHU	24,000	3,729,854	155	1,865

Certain Equipment Costs

Since the purpose of this study was to compare maintenance costs attributable to the method of construction, a comparison was made excluding certain costs. Table 5 gives the costs for the 10 years of occupancy of each type unit for maintenance of water heaters,

Table 2

Yearly M&R Costs by Type of Construction

Year	Total CBU ($)	Cost/Unit ($)	Total MHU ($)	Cost/Unit ($)
1	31,592	219	34,164	171
2	29,107	202	59,076	295
3	44,391	308	63,717	319
*4	45,565	316	449,328	2,247
5	89,186	619	189,122	946
6	96,700	672	175,725	879
7	111,892	777	218,198	1,091
8	104,370	725	474,394	2,372
9	165,209	1,147	519,472	2,597
10	150,807	1,047	321,658	1,608
**	---	---	1,225,000	6,125
10-Year Total	868,818	603.(/yr)	3,729,854	1,865.(/yr)

*MHUs include the $334,600 eaves repair discussed later in the report.
**MHU plumbing replacement over several years.

garbage disposals, dishwashers, ranges, range hoods, and refrigerators (equipment not part of the construction process).

Costs Excluding Interior Painting and Equipment Costs

In Table 6 equipment costs and painting costs are excluded. The difference for unit cost is $1,134 per year versus the $1,262 difference in Table 1.

Maintenance Costs Per Component

Table 7 lists the frequencies of work orders and costs per building component for the two types of units. However, the costs are not directly comparable across the two types of units since there are 200 MHUs and 144 CBUs. Table 8 shows the cost data adjusted by multiplying the MHU costs by 0.72 (144/200). Also shown in Table 8 are the 10-year costs on a unit basis.

Table 8 shows that the total 10-year cost was less than $1,000 for both construction types for 23 of the 80 components. For 42 of the other 57 components, the MHUs had a higher cost.

Neither Table 7 nor 8 includes the eaves cost in year 4 or the waterline replacement cost.

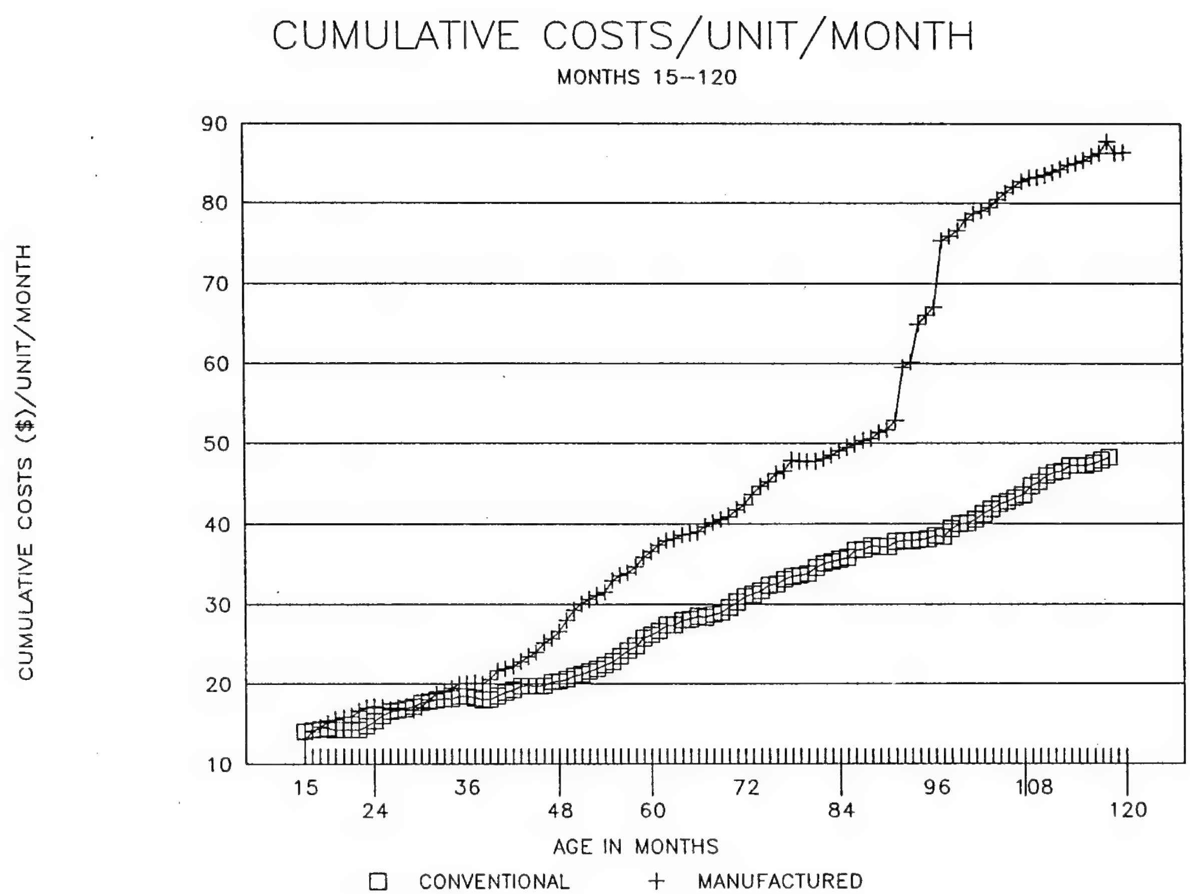


Figure 3. Cumulative cost per unit per month for ages 15 through 120 months.

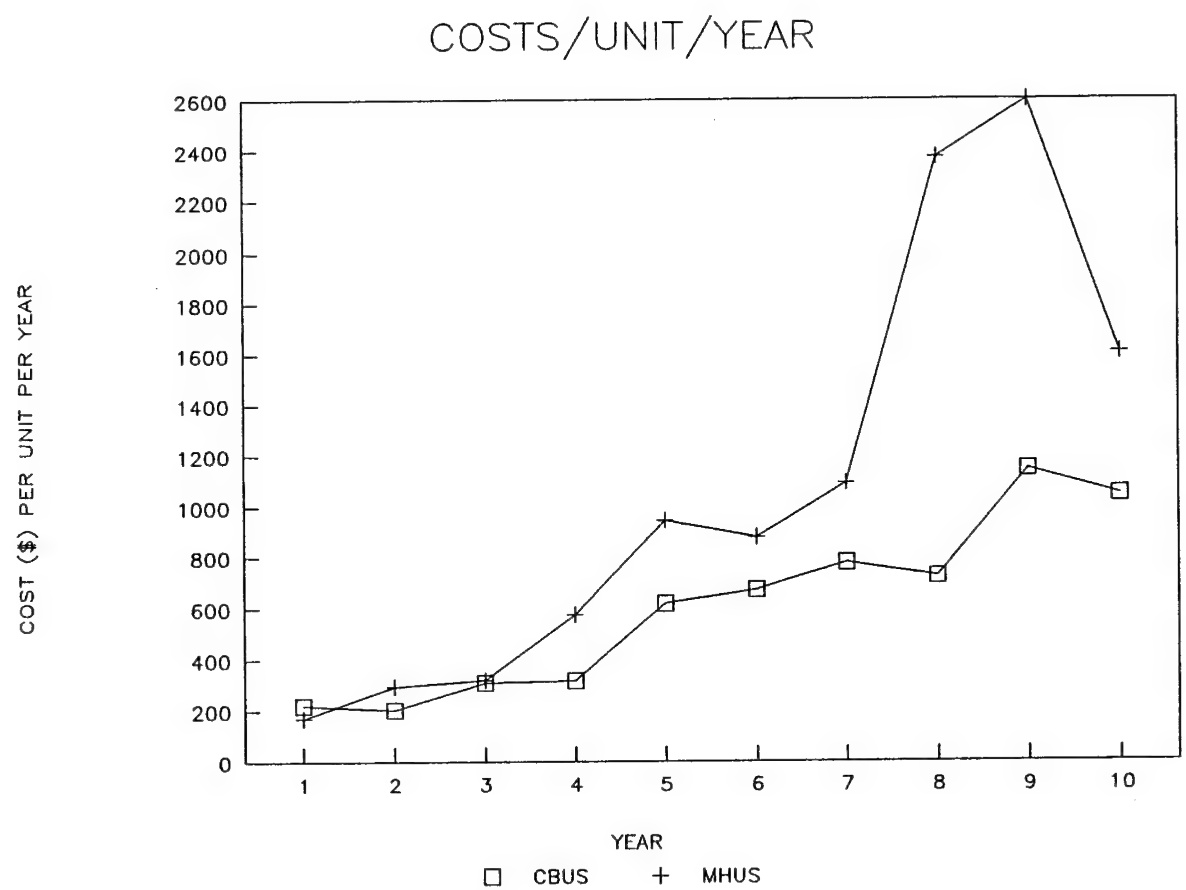


Figure 4. Total costs per unit per year.

Table 3

Interior Painting Costs

Year	Total CBU ($)	Cost/Unit ($)	Total MHU ($)	Cost/Unit ($)
1	603	4	314	2
2	1,234	9	4,486	22
3	7,031	49	13,231	66
4	11,368	79	24,343	122
5	29,720	206	80,485	402
6	49,445	343	74,764	374
7	53,235	370	67,676	338
8	29,583	205	76,157	381
9	55,128	383	102,533	513
10	51,867	360	104,442	522
10-Year Total	289,214	201/yr	548,431	274/yr

Table 4

Yearly M&R Costs Excluding Interior Painting Costs

Year	Total CBU ($)	Cost/Unit ($)	Total MHU ($)	Cost/Unit ($)
1	30,989	215	33,850	169
2	27,873	194	54,590	273
3	37,360	259	50,486	252
4	34,197	237	424,985	2,125
5	59,466	413	108,637	543
6	47,255	328	100,961	505
7	58,657	407	150,522	753
8	74,787	519	398,237	1,991
9	110,081	764	416,939	2,085
10	98,940	687	217,216	1,086
*	---	---	1,225,000	6,125
10-Year Total	579,604	4,025	3,181,423	15,907
Cost/unit/yr ($)	---	402	---	1,591

* Plumbing replacement costs.

Table 5

Certain Equipment Costs

Year	Total CBU ($)	Cost/ Unit ($)	Total MHU ($)	Cost/ Unit ($)
1	4,007	29	6,658	33
2	3,640	25	10,683	53
3	5,810	40	10,121	51
4	4,850	34	18,978	95
5	7,658	53	25,446	127
6	5,990	42	30,316	152
7	8,318	58	22,105	111
8	7,034	49	39,550	198
9	13,199	92	26,819	134
10	11,971	83	18,681	93
10-Year Total	72,478	50/yr	209,359	105/yr

Table 6

Unit Costs Excluding Certain Equipment and Painting Costs

Year	Total CBU ($)	Cost/Unit ($)	Total MHU ($)	Cost/Unit ($)
1	26,982	187	27,192	136
2	24,233	168	43,907	220
3	31,550	219	40,365	202
4	29,347	204	406,007	3,030
5	51,808	360	83,191	416
6	41,265	287	70,645	353
7	50,339	350	128,417	642
8	67,753	471	358,687	1,791
9	96,882	673	390,120	1,951
10	86,969	604	198,535	991
*	---	---	1,225,000	6,125
10-Year Total	507,126	352/yr	2,972,064	1,486/yr

* Plumbing replacement costs.

Table 7

Maintenance Actions Performed and Costs Per Component

Component		Maintenance/Repair Actions				Cost ($)			
No.	Description	CBU		MHU		CBU		MHU	
		(N=18,597)*		(N=30,448)		(Total= 868,818)		(Total= 2,170,254)	
101	Roofing surface	205	(1%)**	458	(2%)	20924	(2%)	347920	(16%)
103	Flashing, vents	35		24		774		1434	
104	Gutters and downspouts	267	(1%)	319	(1%)	4334		4877	
105	Other roof repairs	0		2		0		16	
201	Foundation and anchorage	3		2		24		24	
202	Structure	20		75		377		2851	
203	Insulation	3		0		42		0	
204	Masonry	12		25		537		2282	
205	Exterior siding	4		3		207		280	
206	Exterior doors and frames	755	(4%)	1149	(4%)	21637	(2%)	35535	(2%)
207	Storm and screen doors	900	(5%)	1268	(4%)	33808	(4%)	51303	(2%)
208	Windows and frames	196	(1%)	274	(1%)	5193	(1%)	8380	
209	Storm windows and screens	456	(2%)	422	(1%)	11859	(1%)	9750	
210	Exterior trim	0		2		0		26	
211	Porch/deck	5		5		102		159	
212	Interior drywall	316	(2%)	888	(3%)	9194	(1%)	59989	(3%)
213	Wall coverings and paneling	13		1		249		83	
214	Interior doors	1528	(8%)	1605	(5%)	31503	(4%)	27992	(1%)
215	Interior casework	58		94		1067		2191	
216	Bathroom accessories	257	(1%)	275	(1%)	5612	(1%)	4011	
217	Kitchen accessories, cabinets	404	(2%)	607	(2%)	7553	(1%)	15162	(1%)
218	Drapery hardware	30		102		504		2165	
219	Other exterior/interior	372	(2%)	735	(2%)	19006	(2%)	70268	(3%)
220	Garage doors	762	(4%)	582	(2%)	22908	(3%)	14384	(1%)
301	Resilient flooring	55		380	(1%)	2088		18379	(1%)
302	Carpet and pad	20		94		1112		6298	
304	Underlayment/substrate	2		6		13		70	
305	Other flooring	42		250	(1%)	7076	(1%)	35024	(2%)
401	Paint, walls and ceilings	380	(2%)	588	(2%)	285709	(33%)	530529	(24%)
402	Paint, trim	1		0		20		0	
403	Paint, touchup, interior	127	(1%)	352	(1%)	3484		17903	(1%)
404	Bathtub, shower caulking	292	(2%)	437	(1%)	4409	(1%)	6965	
405	Other interior painting	38		23		881		975	
501	Paint, exterior walls	3		3		92		45	
502	Paint, exterior doors, frames	6		5		141		125	
503	Paint, exterior trim	0		13		0		17767	(1%)
504	Exterior caulking	0		1		0		20	
506	Other exterior painting	2		3		44		75	
601	Heating plant, valve	102	(1%)	56		3617		4000	
602	Motors, blowers, pumps	62		95		4399	(1%)	6674	
603	Ducts	3		42		148		2837	
604	Piping	7		6		190		293	
605	Diffusers, grills	14		66		325		1049	
606	Insulation	0		2		0		61	
607	Heating controls	149	(1%)	101		6612	(1%)	4447	
608	Other heating	577	(3%)	930	(3%)	12832	(1%)	30140	(1%)
701	Cooling coils, compressor	48		55		9719	(1%)	3884	
702	A/C motors, blowers, pumps	111	(1%)	130		10307	(1%)	8987	
703	A/C piping, ducting	7		44		180		1419	
704	A/C refrigerant	394	(2%)	205	(1%)	13860	(2%)	7004	
705	A/C insulation	1		0		7		0	
706	A/C controls	105	(1%)	90		4644	(1%)	3601	
707	Other cooling	1055	(6%)	1487	(5%)	41106	(5%)	61031	(3%)

*N = Number of maintenance actions
**Percents are given for number maintenance actions and costs when the value is 1% or more of the total.

Table 7 (Cont'd)

Component		Maintenance/Repair Actions				Cost ($)			
No.	Description	CBU		MHU		CBU		MHU	
801	Water heater	315	(2%)	748	(2%)	7398	(1%)	31603	(1%)
803	Piping, supply	195	(1%)	1528	(5%)	9245	(1%)	117834	(5%)
804	Faucets and shower heads	868	(5%)	1778	(6%)	26466	(3%)	49206	(2%)
805	Lavatories	493	(3%)	1106	(4%)	10098	(1%)	33728	(2%)
806	Water closets	909	(5%)	1364	(4%)	21034	(2%)	31581	(1%)
807	Bathtub/shower unit	182	(1%)	517	(2%)	4046		13843	(1%)
809	Other plumbing	247	(1%)	830	(3%)	5970	(1%)	31513	(1%)
901	Service entrance	2		2		65		188	
902	Panel box/circuit breakers	78		189	(1%)	3241		8733	
903	Branch circuits	21		21		945		1358	
904	Wall receptacles	366	(2%)	611	(2%)	8237	(1%)	17290	(1%)
905	Doorbells and chimes	2		2		46		34	
906	Light fixtures	1557	(8%)	1551	(5%)	31939	(4%)	38715	(2%)
907	Vents, fans	54		68		1403		1850	
908	Other electrical	53		62		2020		4712	
1001	Garbage disposal	469	(3%)	929	(3%)	10210	(1%)	24077	(1%)
1002	Dishwasher	430	(2%)	1154	(4%)	26180	(3%)	91598	(4%)
1003	Range	978	(5%)	1428	(5%)	26496	(3%)	36729	(2%)
1004	Range hood	108	(1%)	111		2097		1980	
1005	Refrigerator	269	(1%)	603	(2%)	6819	(1%)	21058	(1%)
1006	Other equipment	158	(1%)	243	(1%)	1818		3557	
1201	Water supply	93	(1%)	218	(1%)	2422		9349	
1202	Gas supply	83		162	(1%)	2386		6192	
1203	Electrical service	68		96		6318	(1%)	10214	
1204	Sanitary/sewer lines	5		4		657		191	
1205	Other utility service	0		1		0		8	
1300	Miscellaneous	390	(2%)	741	(2%)	40831	(5%)	152429	(7%)

Table 8

Maintenance Costs Per Component, Adjusted by Number of Units

Component		Costs ($)				
No.	Description	CBU	MHU	MHU Adjusted*	CBU/144**	MHU/200**
101	Roofing surface	20924	347920	250502	145	1740
103	Flashing, vents	774	1434	1032	5	7
104	Gutters and downspouts	4334	4877	3511	30	24
105	Other roof repairs	0	16	12	0	0
201	Foundations and anchorage	24	24	17	0	0
202	Structure	377	2851	2053	3	14
203	Insulation	42	0	0	0	0
204	Masonry	537	2282	1643	4	11
205	Exterior siding	207	280	202	1	1
206	Exterior doors and frames	21637	35535	25585	150	178
207	Storm and screen doors	33808	51303	36938	235	257
208	Windows and frames	5193	8380	6034	36	42
209	Storm windows and screens	11859	9750	7020	82	49
210	Exterior trim	0	26	19	0	0
211	Porch/deck	102	159	114	1	1
212	Interior drywall	9194	59989	43192	64	300
213	Wall coverings and paneling	249	83	60	2	0
214	Interior doors	31503	27992	20154	219	140
215	Interior casework	1067	2191	1578	7	11
216	Bathroom accessories	5612	4011	2888	39	20
217	Kitchen accessories, cabinets	7553	15162	10917	52	76
218	Drapery hardware	504	2165	1559	4	11
219	Other exterior/interior	19006	70268	50593	132	351
220	Garage doors	22908	14384	10356	159	72

Table 8 (Cont'd)

	Component	Costs ($)				
No.	Description	CBU	MHU	MHU Adjusted*	CBU/144**	MHU/200**
301	Resilient flooring	2088	18379	13233	14	92
302	Carpet and pad	1112	6298	4535	8	31
304	Underlayment/substrate	13	70	50	0	0
305	Other flooring	7076	35024	25217	49	175
401	Paint, walls and ceilings	285709	530529	381981	1984	2653
402	Paint, trim	20	0	0	0	0
403	Paint, touchup, interior	3484	17903	12890	24	90
404	Bathtub, shower caulking	4409	6965	5015	31	35
405	Other interior painting	881	975	702	6	5
501	Paint, exterior walls	92	45	32	1	0
502	Paint, exterior doors, frames	141	125	90	1	1
503	Paint, exterior trim	0	17767	12792	0	89
504	Exterior caulking	0	20	14	0	0
506	Other exterior painting	44	75	54	0	0
601	Heating plant, valve	3617	4000	2880	25	20
602	Motors, blowers, pumps	4339	6674	4805	31	33
603	Ducts	148	2837	2043	1	14
604	Piping	190	293	211	1	1
605	Diffusers, grills	325	1049	755	2	5
606	Insulation	0	61	44	0	0
607	Heating controls	6612	4447	3202	46	22
608	Other heating	12832	30140	21701	89	151
701	Cooling coils, compressor	9719	3884	2796	67	19
702	A/C motors, blowers, pumps	10307	8987	6471	72	45
703	A/C piping, ducts	180	1419	1022	1	7
704	A/C refrigerant	13860	7004	5043	96	35
705	A/C insulation	7	0	0	0	0
706	A/C controls	4644	3601	2593	32	18
707	Other cooling	41106	61031	43942	285	305
801	Water heater	7398	31603	22754	51	158
803	Piping, supply	9245	117834	84840	64	589
804	Faucets and shower heads	26466	49206	35428	184	246
805	Lavatories	10098	33728	24284	70	169
806	Water closets	21034	31581	22738	146	158
807	Bathtub/shower unit	4046	13843	9967	28	69
809	Other plumbing	5970	31513	22689	41	158
901	Service entrance	65	188	135	0	1
902	Panel box/circuit breakers	3241	8733	6288	23	44
903	Branch circuits	945	1358	978	7	7
904	Wall receptacles	8237	17290	12449	57	86
905	Doorbells and chimes	46	34	24	0	0
906	Light fixtures	31939	38715	27875	222	194
907	Vents, fans	1403	1850	1332	10	9
908	Other electrical	2020	4712	3393	14	24
1001	Garbage disposal	10210	24077	17335	71	120
1002	Dishwasher	26180	91598	65951	182	458
1003	Range	26496	36729	26445	184	184
1004	Range hood	2097	1980	1426	15	10
1005	Refrigerator	6819	21058	15162	47	105
1006	Other equipment	1818	3557	2561	13	18
1201	Water supply	2422	9349	6731	17	47
1202	Gas supply	2386	6192	4458	17	31
1203	Electrical service	6318	10214	7354	44	51
1204	Sanitary/sewer lines	657	191	138	5	1
1205	Other utility service	0	8	6	0	0
1300	Miscellaneous	40831	152429	109749	284	762
	Totals	868,818	2,170,254	1,562,583		

*The MHU column adjusted by multiplying by 0.72.
**These are costs per unit for the 10 years.

Most of the costs shown in Tables 7 and 8 were for building components independent of type of construction. For example, about $26,000 was spent on the ranges (#1003) for each type, $26,000 for CBUs and $66,000 for MHUs was spent on dishwashers (#1002), and over $28,000 was spent on light fixtures (#906) for each type. Although a large difference existed for painting, Comp 401, this cost depended on rotation of occupants and occupant wear and tear. Complete or extensive quarters painting was done on 407 MHUs and 243 CBUs. The large difference in roofing surface resulted from reroofing in the MHUs in years 8 and 9.

Note the $17,767 cost for exterior-trim painting of MHUs and $0 for CBUs (component no. 503). The exterior trim was to be painted on a cyclic basis. The CBU cycle in 1988 was deferred. Both CBU and MHU exterior-trim painting for 1989-94 was deferred. The most significant costs for components are shown in Table 9.

Table 9

Components With Differing Costs for Type of Construction

Comp		CBU ($)	MHU ($)	MHU ($) Adjusted
101	Roofing Surface	20,924	347,920	250,502
212	Interior Drywall	9,194	59,989	43,192
214	Interior Doors	31,503	27,992	20,154
219	Other Exterior/Interior Repair	19,006	70,268	50,593
220	Garage Doors	22,908	14,384	10,356
301	Resilient Flooring	2,088	18,379	13,233
305	Other Flooring	7,076	35,024	25,217
803	Water Piping	9,245	117,834	84,840
804	Faucet/Shower Heads	26,466	49,206	35,428
805	Lavatories	10,098	33,728	24,284
809	Other Plumbing	5,970	31,513	22,689

Component by Component Analysis of Table 9

A repair action as discussed below was either (a) a service order or (b) a task accomplished under the "cyclic maintenance" (CM) program conducted in some years or a task accomplished under vacant quarters maintenance (VQM). In CM or VQM, the maintenance personnel corrected all deficiencies found during their inspection or wrote a service order to make the repair. Thus, many actions done during CM/VQM would not have been done on a called-in service order as they were very minor in nature, such as a chipped floor tile or scratch on a door.

101 - Roofing Surface

	# Repair Actions	# Actions > $100
CBUs	507	63
MHUs	458	170

Comments - The largest repair for CBUs was $877 to replace four squares of shingles. Until 1992, the largest action cost $859. As stated in the 5-year report, an inspection of the shingles on the MHUs showed low quality installation—e.g., too few staples were used per shingle. Additionally, the MHUs are in a very windy part of the base and low pitched shingle roofs were not appropriate.

212 - Interior Drywall

	# Repair Actions	# Actions > $100
CBUs	316	7
MHUs	888	149

Comments - Most actions were minor repairs done during CM or VQM. For MHUs, the largest cost was $1,372 for a ceiling repair after a water leak. Most of the 149 actions costing more than $100 were repairs after water leaks, with a total cost of $35,137.

214 - Interior Doors

	#Repair Actions	$ Actions > $100
CBUs	1528	40
MHUs	1605	20

Comments - Most repairs were very minor and were done during CM or VQM. i.e., any little scratch/dent was repaired, hinges tightened, door stops replaced, etc.

219 - Other Exterior/Interior

	# Repair Actions	# Actions > $100
CBUs	372	72
MHUs	735	267

Comments - This component includes venetian blinds. Of the 372 CBU actions, 317 were on venetian blinds and all of the 72 actions over $100 were for venetian blinds. Similarly for MHUs, 679 actions were for venetian blinds, and all but two of the 267 actions over $100 were for replacing venetian blinds.

220 - Garage Doors

	# Repair Actions	# Actions > $100
CBUs	762	33
MHUs	582	15

Comments - Most of the actions for both CBUs and MHUs were done on CM or VQM. Most of these were minor—-renail strips of wood, adjust cabling, adjust locks, etc.

301 - Resilient Flooring

	# Repair Actions	# Actions > $100
CBUs	55	4
MHUs	730	44

Comments - Most of the actions were accomplished during CM or VQM and most were for small repairs—replace/repair a few tiles. The much larger number for MHUs is partially due to the modular construction being less rigid, with settling causing tile cracking. Additionally, the MHUs' floors received much water damage from water pipe leaks. As the MHUs piping is being replaced, many of the floors are being carpeted because of floor tile condition and the higher cost to repair/replace tiles versus laying carpet over them.

305 - Other Flooring

	# Repair Actions	# Actions > $100
CBUs	42	2
MHUs	250	70

Comments - One of the CBU actions was a floor replacement, costing $5,795. Again, damage from water piping leaks was a cause for many of the MHU actions. For MHUs, 66 actions were on CM or VQM. Four of those over $100 were over $800—$1,909, $2,067, $2,164, and $4,294—the total of the 70 actions was $29,072.

0803 - Water Piping

	# Repair Actions	# Actions > $100
CBUs	195	23
MHUs	1,528	413

Comments - The large number of actions for MHUs verifies the water piping problem discussed later in this section of the report. USACERL Technical Report FF-93/09 (see page 8, footnote 11) discusses the water piping problem in detail. Use of inappropriate acetal fittings created numerous piping failures and resulted in the decision to replace all water piping in the MHUs at a cost of over $1.2M.

0804 - Faucet/Shower Heads

	# Repair Actions	# Actions > $100
CBUs	868	32
MHUs	1,778	46

Comments - Over 300 of the CBU and over 800 of the MHU actions were accomplished during normal CM or VQM, indicating indicating many minor actions such as leaking heads.

0805 - Lavatories

	# Repair Actions	# Actions > $100
CBUs	593	1
MHUs	1,106	66

Comments - Over half of the CBU actions were done on CM or VQM. Some 212 of the CBU actions were recaulking sinks. Similarly, over half of the MHU actions were done on CM or VQM. Some 243 of the MHU actions were recaulking sinks. Most of the 66 MHU actions over $100 were replacements. These actions are done on CM/VQM to put the unit in good shape.

0809 - Other Plumbing

	# Repair Actions	# Actions > $100
CBUs	247	7
MHUs	830	45

Comments - Most of the actions for CBUs and MHUs were CM or VQM. For CBUs, 169 were repairs on drains, and for MHUs, 485 were repairs on drains.

Table 10 groups the Table 8 data into the 12 major building component codes (Appendix C). Although the 0201-0220 structure is a high cost item, Table 8 shows most of these costs are related to doors and windows, and some of the damage to these items was caused by the occupant. Note the plumbing costs for the MHUs is 2.6 times that for the CBUs.

Water Piping Problems Discussion

The manufacturer used polybutylene piping in the MHU units. The piping was installed in the building modules at the plant in Southern California and many connections made after the modules were assembled at Fort Irwin (after 200 miles of transportation).

These manufactured apartments are two-story fourplexes; two units above two units. Piping runs through walls, the ceiling of the first floor units (i.e., the floor of the upper units) and under the first floor units in the crawl space.

There have been many leaks in the piping with several major breaks in a "tee" joint in the ceiling of the first floor units of the MHUs. A detailed analysis of plumbing service orders shows a higher cost for MHUs for the category leaking or broken piping. Costs for each of the 10 years are shown in Table 11.

Most leaks are breaks of the hard plastic tees and valves, usually under the crimped metal band. The problem is so bad that all piping is to be replaced at an estimated cost of $1.2 million.

Table 10

Maintenance Actions Performed and Costs for Component Group, 10-Year Summary

Component Group	Description	Maintenance/Repair Actions: CBU (N=18,597)		Maintenance/Repair Actions: MHU (N=30,448)		Cost ($): CBU (Total = 868,818)		Cost ($): MHU (Total = 2,170,254)		Cost ($): MHU Adjusted (Total = 1,562,583)
0101-0105	Roofing	507	(3%)	803	(3%)	26,032	(3%)	354,248	(16%)	255,059
0201-0220	Structure	6,094	(33%)	8,114	(27%)	171,382	(20%)	306,835	(14%)	220,921
0301-0305	Floor coverings	119	(1%)	730	(2%)	10,289	(1%)	59,772	(3%)	43,036
0401-0405	Interior painting	848	(5%)	1,400	(5%)	294,504	(34%)	556,372	(26%)	400,588
0501-0506	Exterior painting	11	(0%)	25	(0%)	277	(0%)	18,032	(1%)	13,177
0601-0608	Heating	914	(5%)	1,298	(4%)	28,123	(3%)	49,500	(2%)	35,640
0701-0707	Air conditioning	1,721	(9%)	2,011	(7%)	79,822	(9%)	85,926	(4%)	61,867
0801-0809	Plumbing	3,209	(17%)	7,871	(26%)	84,257	(10%)	309,307	(14%)	222,701
0901-0908	Electrical	2,133	(11%)	2,506	(8%)	47,897	(6%)	72,880	(4%)	52,474
1001-1006	Equipment	2,412	(13%)	4,468	(15%)	73,620	(8%)	178,998	(8%)	128,879
1201-1205	Utility service	249	(1%)	481	(2%)	11,783	(1%)	25,953	(1%)	18,686
1300	Miscellaneous	390	(2%)	741	(2%)	40,831	(5%)	152,429	(7%)	109,749

Table 11

Water Piping Costs

Year	CBUs ($)	MHUs ($)
1	776	1,134
2	473	2,524
3	408	758
4	408	1,769
5	108	2,462
6	487	4,870
7	557	12,458
8	1,665	33,270
9	1,978	39,558
10	2,386	19,030
Total	9,245	117,834

This problem is not new in the plastic pipe industry. A "60 Minutes" television program shown in December 1990 described many problems in the Southwest in using acetal fittings with these plumbing materials.

Summary of M&R Costs

The two major deficiencies found in the MHUs to date were the improperly installed hingeable eaves and the water piping. Both of these were caused by improper design (eaves), improper material specification, and poor quality workmanship (water piping). Neither of these problems is considered a defect due to the type of construction—manufactured. Although not due to type of construction (in this instance at Fort Irwin), the project will cost the Army an additional $334,600 (eaves repair) + $1,225,000 (piping replacement) = $1,559,600 ($7,800 per unit), which would not have occurred if the same conventional construction had been used as in the 144 units. Ignoring these two costs, the MHUs were still higher. In year 10, the MHUs cost $1,608 - $1,047 = $561/unit more (statistically significant) than the CBUs overall and $991 - $604 = $387 more excluding certain equipment and painting costs. About $79 of these differences was due to water piping alone. The $561 - $79 = $482 difference for overall M&R costs in year 10 is significant.

For the 10 years, the MHUs cost $1,865 - $603 = $1,262/unit/yr more than the CBUs overall and $1,486 - $352 = $1,134/unit/yr more excluding certain equipment and painting costs. About $671 of these differences was due to water piping alone.

7 ENERGY COSTS

Comparisons of gas and electricity consumption began in May 1984, since most MHUs were not occupied before then.

Electricity Consumption

The average quarterly electric usage (in kWh) per housing unit is shown in Table 12 and Figure 5. The MHUs had higher average consumptions than the CBUs in 17 of the 40 quarters and higher in 9 of the 10 summer quarters, Jun-Aug. For the entire 120-month data collection period, an MHU used an average total of 93,640 kWh, while a CBU used an average total of 93,654 kWh. This was a difference of 6 kWh ÷ 120 months = 0 kWh/month. For the 10 years the two types of housing used the same amount of electricity. Average yearly electricity usage is shown in Figure 6.

Gas Consumption

The type of fuel used was liquid propane (LP). LP is delivered to a central facility on post and is converted to gas and distributed to housing units through underground pipes. The average quarterly usage (cu ft) per housing unit is shown in Table 13 and Figure 7.

For the 120-month period, an MHU used an average total of 191,260 cu ft while a CBU used an average total of 176,410 cu ft. The MHUs had higher average consumptions in 33 of the quarters, always higher in the winter, Dec-Feb, and in eight of the ten spring quarters, Mar-May. This is a difference of 14,850 cu ft ÷ 120 months = 124 cu ft/month. At the June cost of $.01663/cu ft, an MHU cost $2.06 more than a CBU for gas per month. Average yearly gas usage is shown in Figure 8.

Statistical Analysis of Consumption

One-way analysis of variance tests showed significant differences among the10 years of data for gas and electricity consumption for each of the types of construction.

T-tests were performed comparing the construction types for each year for both gas and electricity consumption. Results are shown below:

Average Consumptions for Each Year

		1	2	3	4	5	6	7	8	9	10
Electricity	MHUs	8613	9027	8895	8959	9658	9358	9279	10180	9904	9882
(kWh)	CBUs	8195	8757	9093	9255	9654	9223	9054	10251	10002	10200
Gas	MHUs	21340*	18020*	19320	19890	19060	18320*	20310*	18420*	19590*	17010
(Cu Ft)	CBUs	19200	16810	19010	19360	18170	16650	17470	16050	17600	16020
Total Energy	MHUs	89.79*	82.12	85.36	86.96	87.39	84.28*	89.53*	87.40*	89.77	82.45
(MBtu/sf)	CBUs	82.40	77.83	85.29	86.62	85.23	79.26	80.96	81.04	84.72	79.89

An asterisk (*) means there is a statistically significant difference between the types of construction for average unit consumption for a year. (Tests were at the 99 percent confidence level.) Note there were no significant differences for electricity consumption.

Total Energy Consumption

The total energy consumption for the housing units is shown in Table 14. It was calculated by converting the gas and electricity consumption data to MBtu/KSF. (One cubic foot of propane gas = 2,618.5 Btu and one kWh of electricity = 3,413 Btu.) The gross area of the housing units is approximately 1,160 sq ft for MHUs and 1,120 sq ft for CBUs, so multipliers of 1000/1160 = 0.86 and 1000/1120 = 0.89, respectively, were used to convert usage to MBtu/KSF.

The two types used comparable amounts of energy: MHUs - 71 MBtu/yr and CBUs - 70 MBtu/yr. *Both of these are about 17 to 18 percent higher than the DOD Design Energy target of 60 MBtu/yr.*

Cost Comparison Summary

The averages for dwelling unit energy consumption and cost for the 10-year period (Jun 1984 to May 1994) are given in Table 15. The MHUs on the average have cost $25 more (2 percent) per year for gas and electricity than the CBUs.

Meter Problems

Many meters have become defective over the past 10 years. For the CBUs, 49 electric and 9 gas meters have failed while for the MHUs, 20 electric and 5 gas have failed.

Comments

The data in Chapter 5 (better air tightness and higher furnace efficiencies for the MHUs) would indicate the MHUs should use less energy than the CBUs. However, this is offset by the higher overall heat loss of the MHUs. Detailed energy simulations (performed using the Building Loads Analysis and System Thermodynamics* program) indicate two design/construction features that cause the higher wall-heat loss: the MHUs have more window/door glass area; and the MHUs have single-pane glass while the CBUs have thermal-pane. Additionally, the CBUs were built on concrete slabs while the MHUs have crawl spaces, which are less energy efficient.

*The Building Loads Analysis and System Thermodynamics (BLAST) program was developed by USACERL and is used throughout the Department of Defense for military construction projects.

Table 12

Average Quarterly Electricity Consumption (kWh) Per Housing Unit

	1984 Jun-Aug	Sep-Nov	1984-5 Dec-Feb	1985 Mar-May	Jun-Aug	Sep-Nov	1985-6 Dec-Feb	1986 Mar-May
MHU	3492	2005	1399	1737	4053	1743	1470	1763
CBU	3263	1925	1353	1655	3752	1857	1410	1738
	1986 Jun-Aug	**Sep-Nov**	**1986-7 Dec-Feb**	**1987 Mar-May**	**Jun-Aug**	**Sep-Nov**	**1987-8 Dec-Feb**	**1988 Mar-May**
MHU	3951	1778	1500	1725	3644	2191	1483	1702
CBU	3683	1934	1630	1813	3550	2411	1494	1768
	1988 Jun-Aug	**Sep-Nov**	**1988-9 Dec-Feb**	**1989 Mar-May**	**Jun-Aug**	**Sep-Nov**	**1989-90 Dec-Feb**	**1990 Mar-May**
MHU	3738	2366	1550	1996	3892	2192	1523	1750
CBU	3513	2445	1610	2024	3634	2180	1478	1823
	1990 Jun-Aug	**Sep-Nov**	**1990-1 Dec-Feb**	**1991 Mar-May**	**Jun-Aug**	**Sep-Nov**	**1991-2 Dec-Feb**	**1992 Mar-May**
MHU	3796	2348	1473	1628	3654	2717	1664	2113
CBU	3406	2252	1600	1730	3616	2650	1680	2237
	1992 Jun-Aug	**Sep-Nov**	**1992-3 Dec-Feb**	**1993 Mar-May**	**Jun-Aug**	**Sep-Nov**	**1993-4 Dec-Feb**	**1994 Mar-May**
MHU	4014	2486	1566	1855	4061	2406	1535	1880
CBU	3934	2322	1691	1974	3926	2578	1545	2151

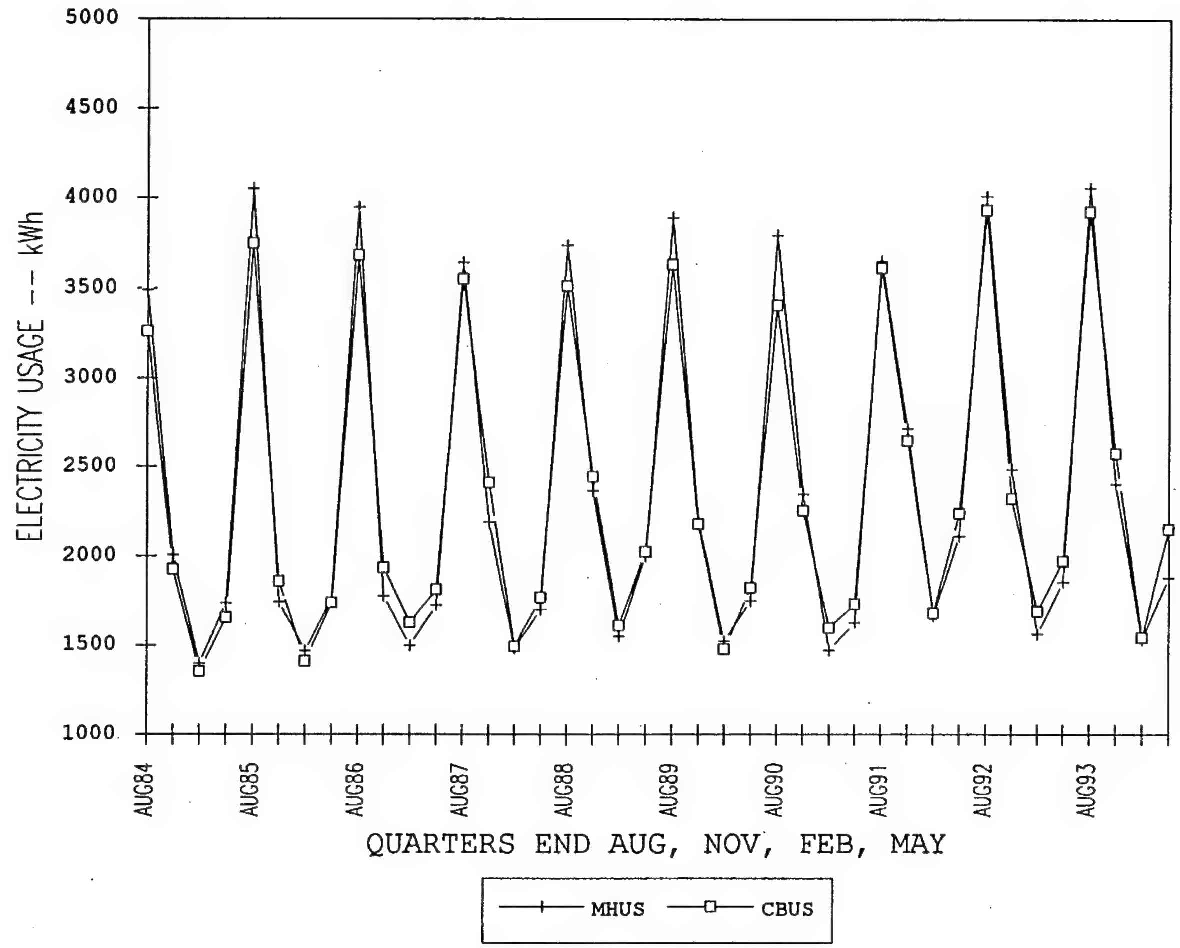


Figure 5. Quarterly electricity consumption.

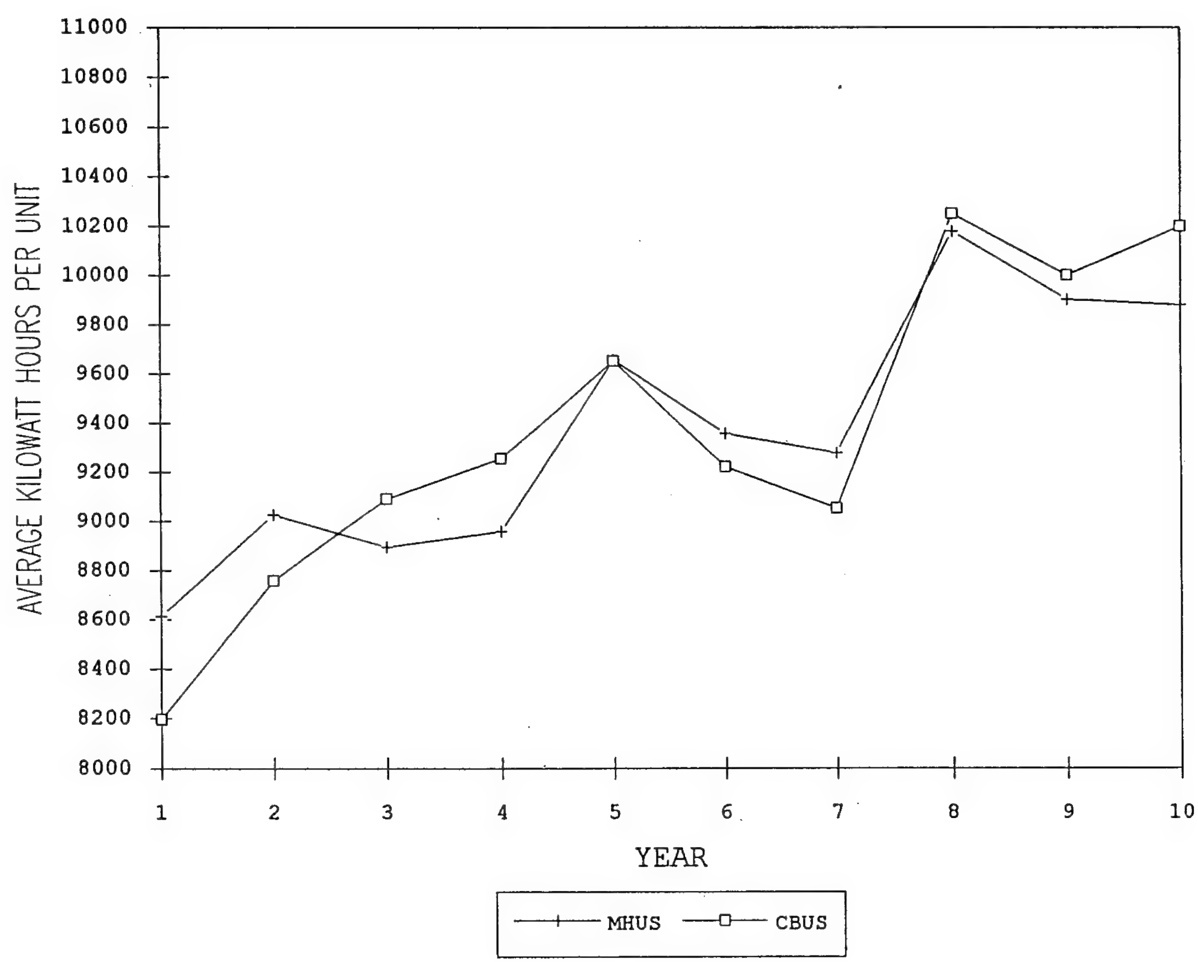


Figure 6. Yearly electricity consumption.

Table 13

Average Quarterly Gas Consumption (cu ft) Per Housing Unit

	1984 Jun-Aug	Sep-Nov	1984-5 Dec-Feb	1985 Mar-May	Jun-Aug	Sep-Nov	1985-6 Dec-Feb	1986 Mar-May
MHU	1890	4400	10050	5130	1890	4440	7670	4020
CBU	1780	3730	9200	4500	1840	3970	7080	3950

	1986 Jun-Aug	Sep-Nov	1986-7 Dec-Feb	1987 Mar-May	Jun-Aug	Sep-Nov	1987-8 Dec-Feb	1988 Mar-May
MHU	1800	3810	9340	4390	1910	3300	9930	4740
CBU	2130	3520	9070	4500	2160	3430	9500	4460

	1988 Jun-Aug	Sep-Nov	1988-9 Dec-Feb	1989 Mar-May	Jun-Aug	Sep-Nov	1989-90 Dec-Feb	1990 Mar-May
MHU	1880	3490	10000	3700	1920	3400	9080	3910
CBU	1960	3250	9400	3550	1960	3140	8160	3390

	1990 Jun-Aug	Sep-Nov	1990-1 Dec-Feb	1991 Mar-May	Jun-Aug	Sep-Nov	1991-2 Dec-Feb	1992 Mar-May
MHU	1850	3350	9130	5980	1820	3290	8960	4250
CBU	1790	2920	7810	4950	1730	2780	7590	3950

	1992 Jun-Aug	Sep-Nov	1992-3 Dec-Feb	1993 Mar-May	Jul-Aug	Sep-Nov	1993-4 Dec-Feb	1994 Mar-May
MHU	2400	3850	9720	4200	2110	3830	8090	3640
CBU	1720	3240	8870	3730	1990	3120	7660	3240

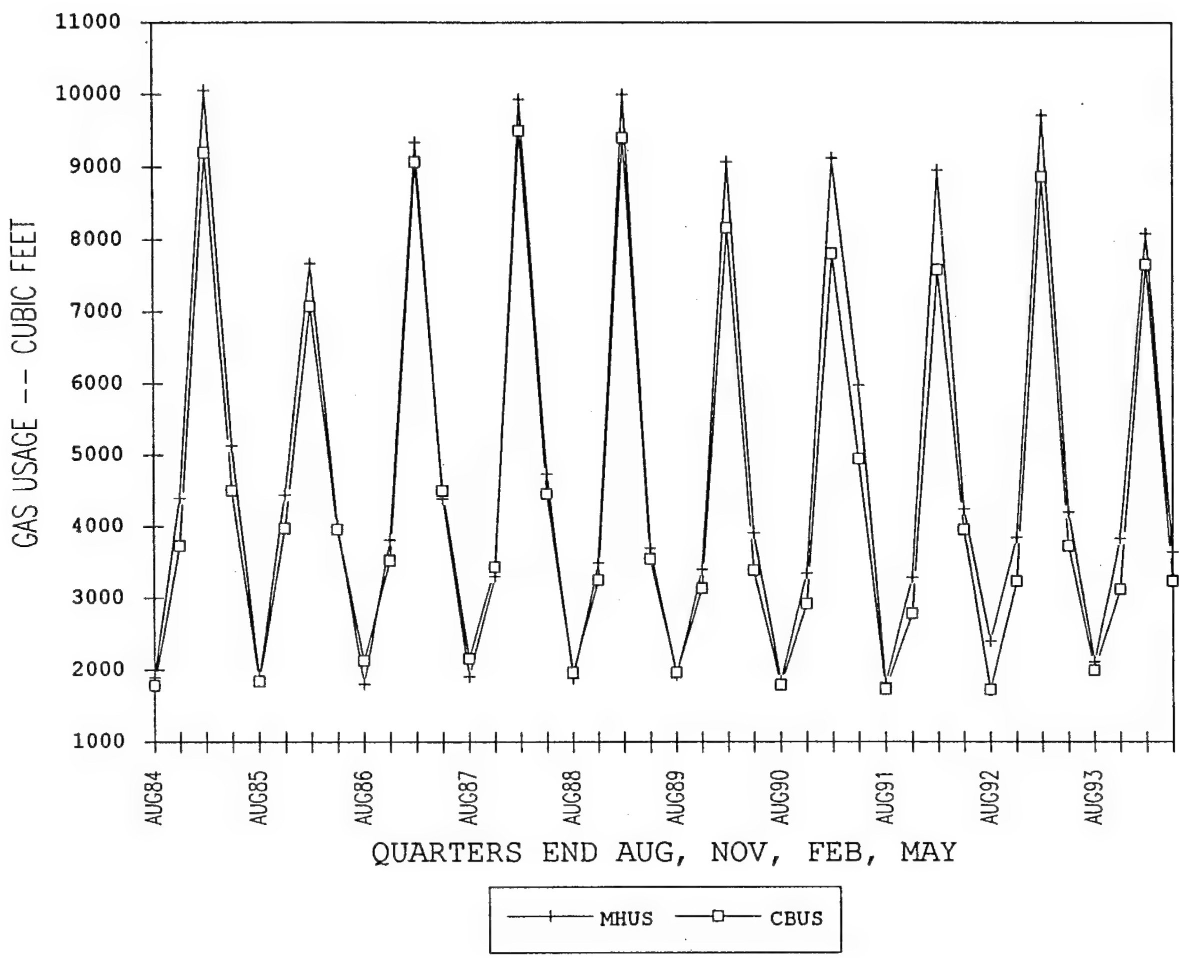


Figure 7. Quarterly gas consumption.

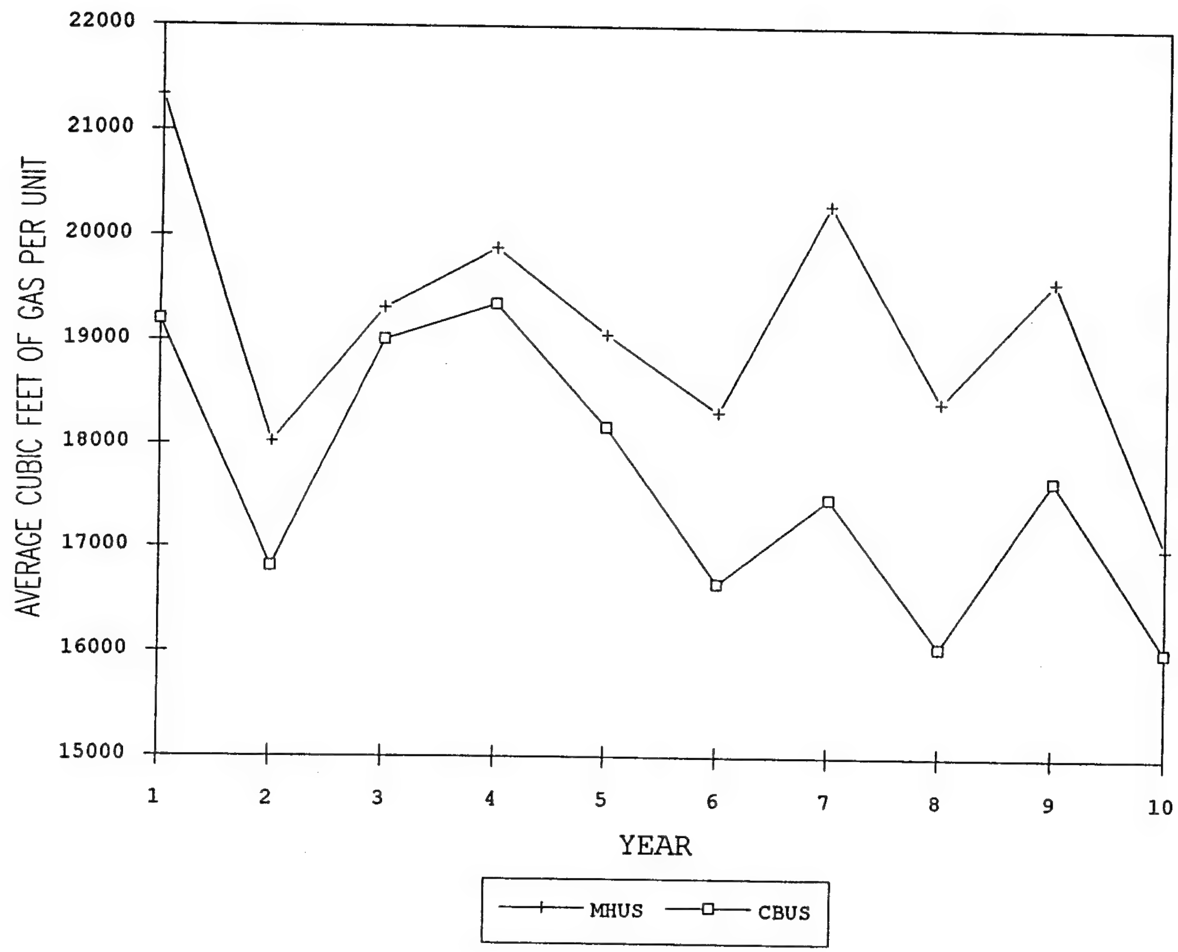


Figure 8. Yearly gas consumption.

Table 14

Total Energy Consumption

	MHU		CBU	
	Gas (cu ft)	**Electricity (kWh)**	**Gas (cu ft)**	**Electricity (kWh)**
10 year total	191,260	93,640	176,410	93,654
Yearly average	19,126	9,364	17,641	9,365
MBtu/year	50.08	31.96	46.19	31.96
Total energy per year	82.04 MBtu		78.16 MBtu	
Conversion to MBtu/ksq ft	70.55 MBtu/yr*		69.56 MBtu/yr*	

(MBtu = million British thermal units)
* The DOD Design Energy target is 60 MBtu/yr.

Table 15

Ten-Year Summary of Energy Consumption and Cost

	MHU		CBU	
	Gas (cu ft)	**Electricity (kWh)**	**Gas (cu ft)**	**Electricity (kWh)**
Average Consumption/Year Per Housing Unit	19,126	9,364	17,641	9,365
Average Cost/Year Per Housing Unit	$318	$895	$293	$895
Total Cost/Year	$1,213		$1,188	

8 CONCLUSIONS AND RECOMMENDATIONS

Maintenance Costs

After 10 years' occupancy, the two types of units have a significant difference in maintenance costs. For all 10 years, the MHUs cost $1,134 more per unit per year for maintenance (ignoring interior painting and equipment costs, such as ranges and dishwashers). This is a 322 percent difference in costs ($1,486/yr for MHU vs $352/yr for CBU, Table 6).

Energy Costs

MHUs cost slightly more than CBUs for energy used—$25 more per unit per year for gas and electricity.

Water Piping

The MHU water piping is being replaced. Piping failures not only significantly increased the cost, but also affected the morale of families in units with major problems. There is a significant difference to the government in costs between the two types of construction due to this problem.

Design and Construction Problems

Manufactured Units

Fitting and valves for the polybutylene piping. As explained in the 8-year report, the acetal valves and fittings used were not appropriate for use with chlorine-treated or chlorinated water. Copper, brass, or polybutylene should be used. Also, the piping was improperly installed in many cases, resulting in crushed or flattened piping with nails sometimes driven into it. Consequently, the government paid some $1.225 million to correct the problem by installing new lines in all 200 units. The failure of the acetal valves and fittings was not a problem unique to the units constructed at Fort Irwin, but occurred throughout the Southwest in the early 1980s.

Hinged eaves. The eaves were hinged to allow a module width that was transportable over the interstate highways. The single, flimsy metal straps were not appropriate to fasten the eaves, and the government paid $0.335 million to properly fasten them to the structure.

Asphalt shingles. Asphalt shingles were used on low pitch roofs in a location subject to high winds. (New housing uses concrete Spanish-type tiles.) Also, construction was substandard as many strips had only one or two fasteners rather than the four specified by the Uniform Building Code.

Floor covering. Some cracking and buckling of resilient floor covering in the second floor units was due possibly to settling and movement of the modules. Costs for floor covering for the MHUs was four times that for the CBUs of the 10 years.

Gutters and downspouts. Gutters and downspouts were not needed for these units. At most, they need gutters over entranceways. As the gutters and downspouts fell, due to high winds, they were not replaced.

Conventionally Built Units

Asphalt Shingles. These units experienced the same roofing problems as the MHUs, but not to the same extent. Their location on post was in less of a "wind tunnel." However, the same construction process quality defect was found—an inadequate number of staples used to fasten the shingle strips.

Garage Doors. The garage doors for these units were of poor design. Lightly built, the doors were significantly warped.

Specification Changes

One purpose of the 5-year study as originally conceived was to use the test comparison results to improve the specifications used for manufactured housing. The original specifications failed to ensure good construction in two areas, roofing and water piping.

Roofing

The specification was for "220# Class A wind resistant type fiberglass shingles," and "Starter course shall be doubled and shingles shall be attached with four galvanized nails or staples per shingle, in accordance with FS SS-S-0300."

The housing is in an area subject to very high winds, so the low-pitch shingle roofing was not appropriate for the locale. Another problem was reported in the 5-year report, USACERL TR P-90/11 (1990). An inspection of the roofs revealed poor installation with fewer than four staples per shingle frequently observed. These two problems resulted in complete reroofing in years 8 and 9.

Water Piping

The specification stated "All interior water piping within the building shall be polybutylene pipe and fittings, conforming to ASTM D 3309, 180 degrees, at 100 psi." Corps of Engineers Guide Specification (CEGS) 15400 also allowed the use of the acetal fittings. This CEGS and future specific project specifications should state that designers will not allow the use of acetal valves or fittings in distribution systems containing chlorine treated or chlorinated water. Copper, brass, or polybutylene valves and fittings should be used. Future specifications on polybutylene piping use in Army family housing should be very clear on this point.

Additionally, the specifications and drawings required installation of gutters and downspouts. This requirement was an error as Fort Irwin is located in the high desert, and these components are not needed. Most have blown loose and been removed. Project specifications for housing in the Fort Irwin area should not include gutters and downspouts unless needed over doorways or stairs.

Recommendations for Future Manufactured Housing

- Design reviews for unique features such as hinged eaves.
- Review of "different" types of materials such as polybutylene for water piping to ensure materials are appropriate.
- Quality assurance inspections of construction to detect problems such as improper installation of the polybutylene piping, shingles, and eaves.

APPENDIX A: Description of the MHU Construction Process

The MHUs were not typical of manufactured housing in that the manufacturer was not allowed to design the housing. The contractor was given designs based on the fourplexes being built using conventional construction methods and was required to manufacture accordingly. Thus, it is possible that given the opportunity to both design and manufacture, the final structure might be somewhat different and less costly.

The concept used was to manufacture complete modules in the factory, which could be transported (about 200 miles from the factory in the Los Angeles area to Fort Irwin) and assembled on site. Thus, the process involved several steps: manufacture of complete modules (electrical, plumbing, HVAC, etc., included at the plant); construction of perimeter footings at the site; transportation of modules to the site; assembly of the modules into fourplexes using a crane; joining modules together including connection of piping and electrical wiring; application of stucco exterior finish; roofing at the module joints and securing of eaves; and on-site construction of the garages. On-site construction was limited by contract to foundations, utilities, slabs, garages, exterior finishes, final painting, exterior stairways and balconies. Figures A1 through A6 show factory work, modules on trucks, crane assembly and a completed fourplex without stucco and garages.

The eaves were attached using flat metal straps and folded onto the roof for transportation (this decreased the width for highway transportation). Upon assembly at the site, the eaves were folded down and secured with only a few nails. This was a defect in the design/construction, as the eaves began to loosen; one fell to the ground. All eaves were then permanently secured at a cost of over $300,000 ($6,000 per building).

The MHUs are essentially the same as the CBUs; floor plans of the two types are very similar. Figures A7 through A10 show sample floor plans for the MHUs and the CBUs.

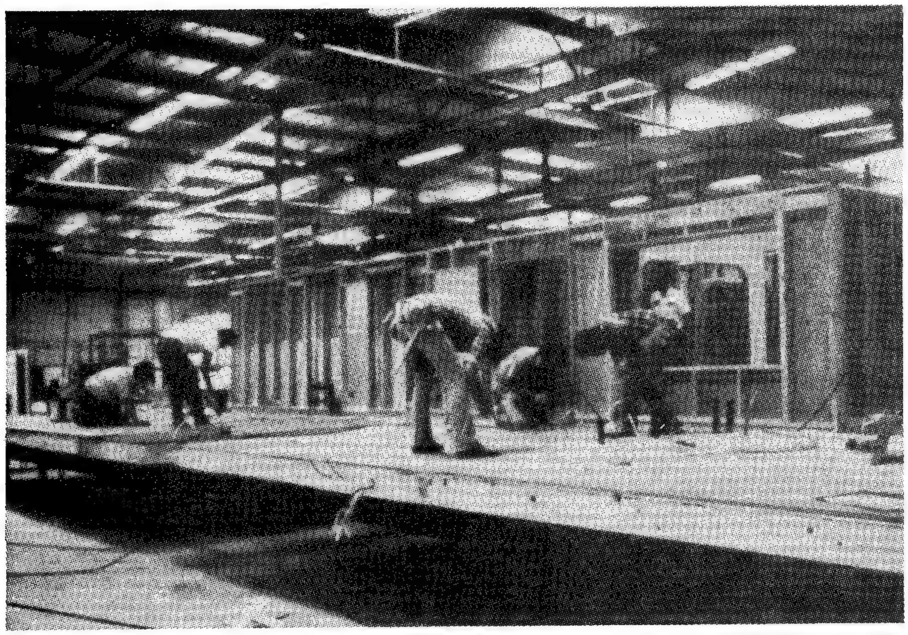


Figure A1. Construction in the factory.

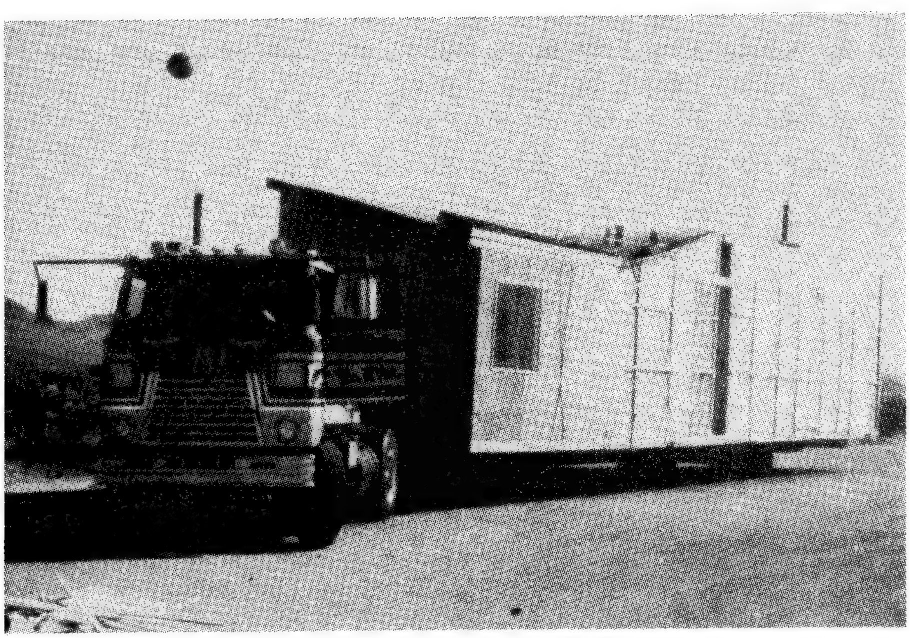


Figure A2. Two modules loaded on truck.

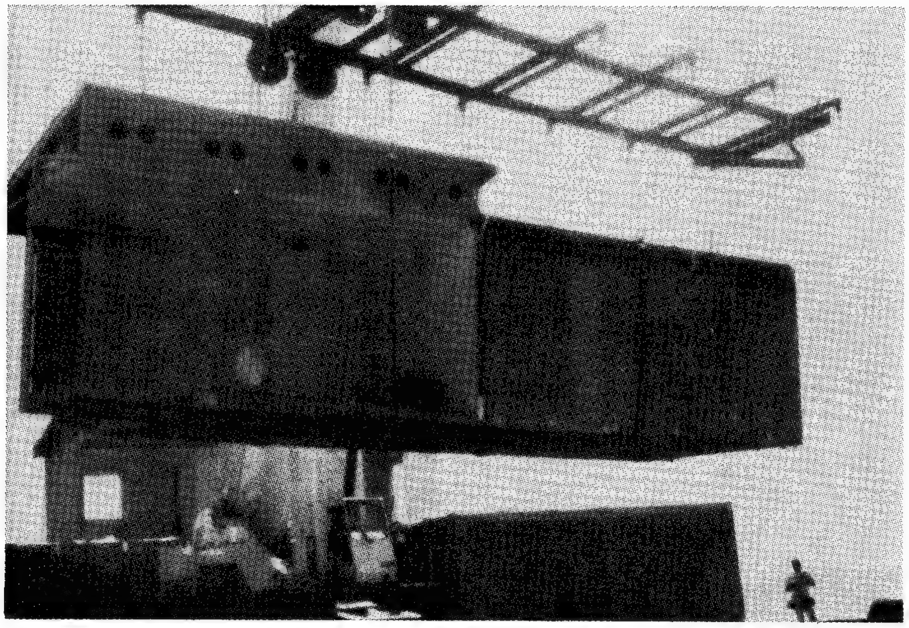


Figure A3. Module being set in place by crane.

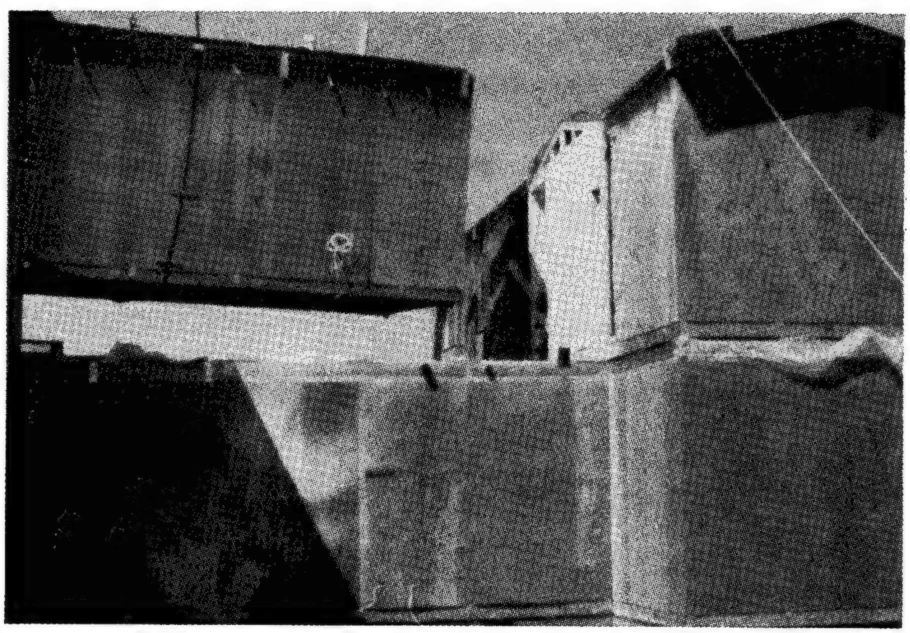


Figure A4. Near completion of one building.

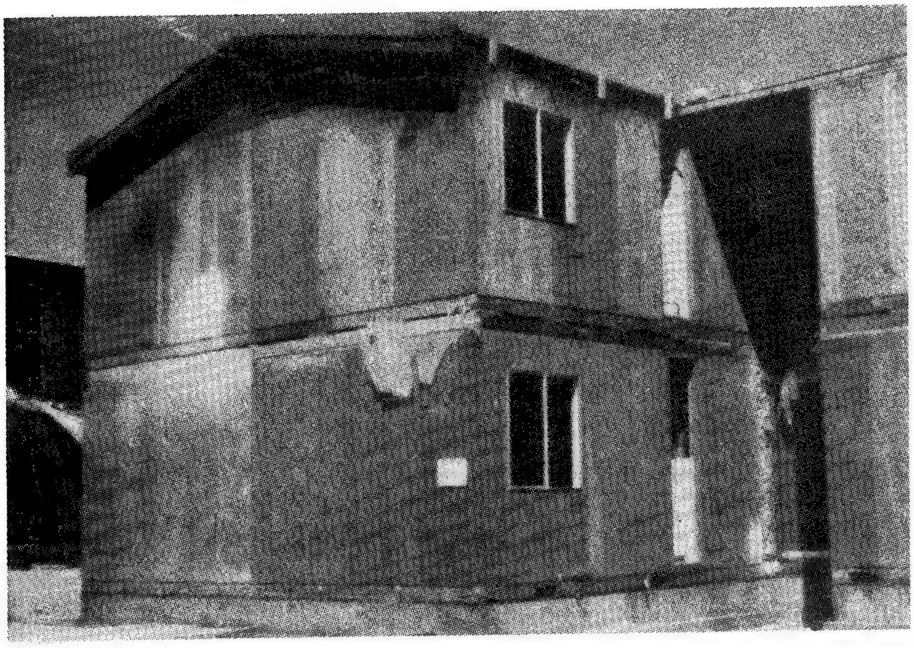


Figure A5. Completed assembly of modules.

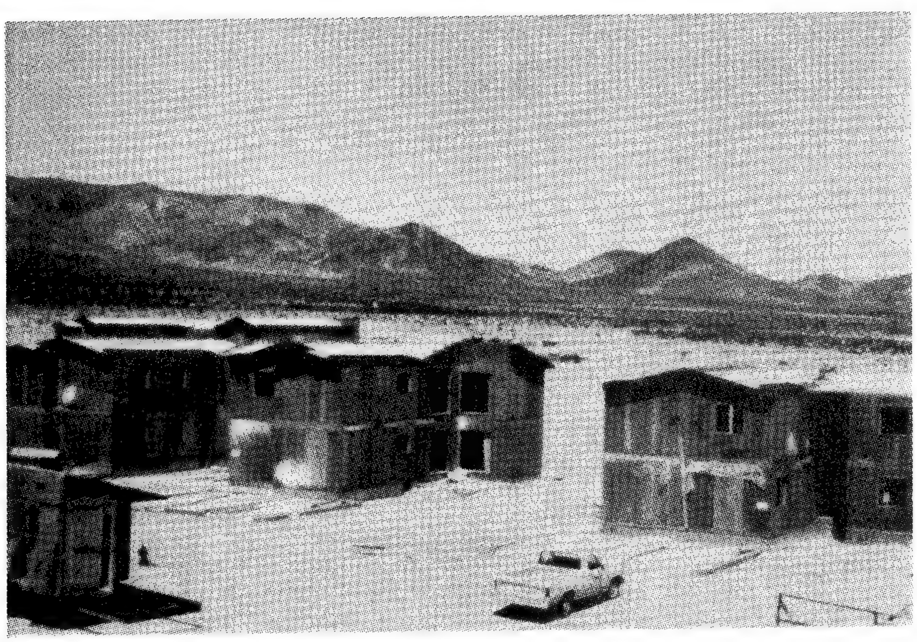


Figure A6. Overview of buildings without garages.

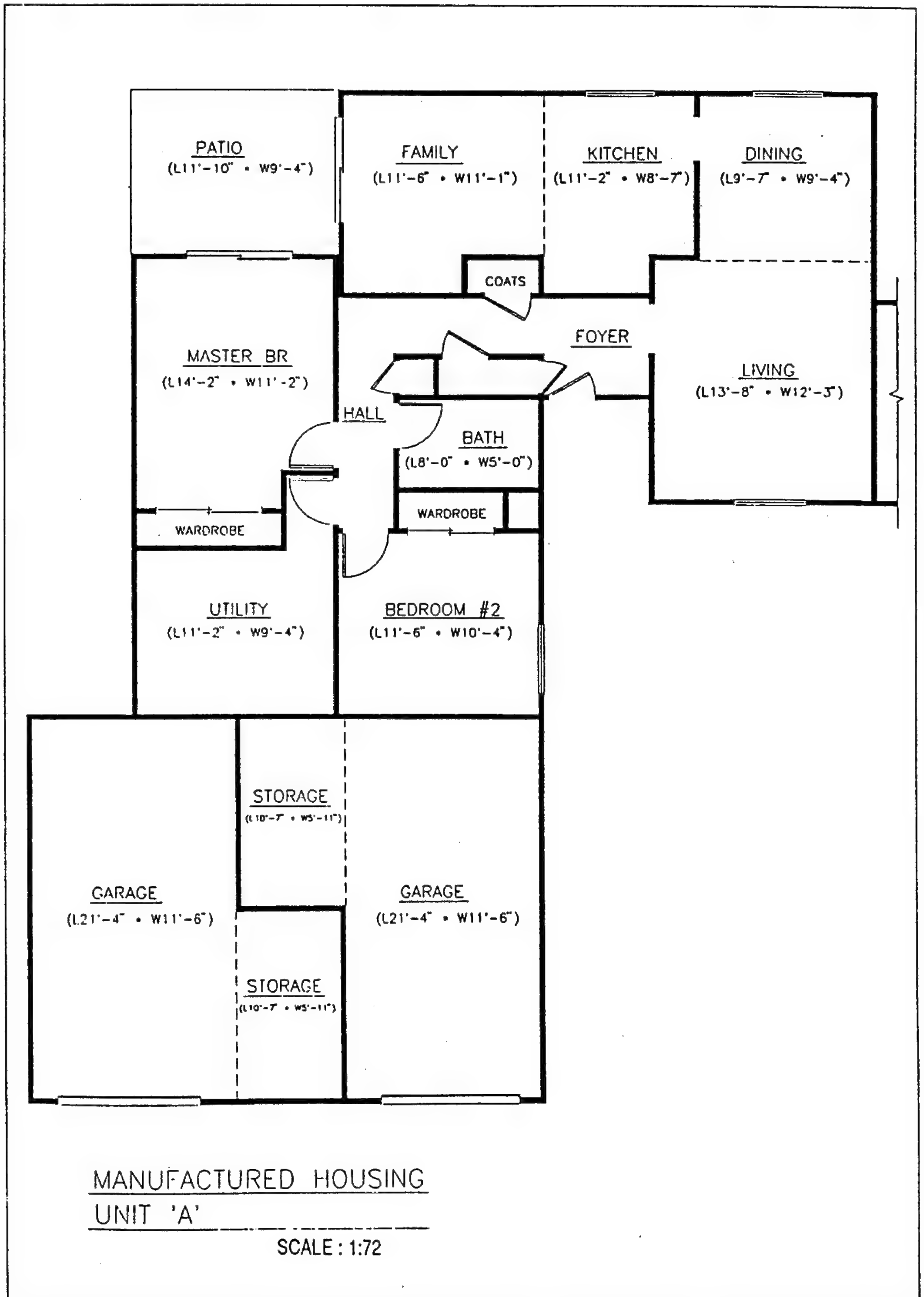


Figure A7. Floor plan for first floor MHU, Type A.

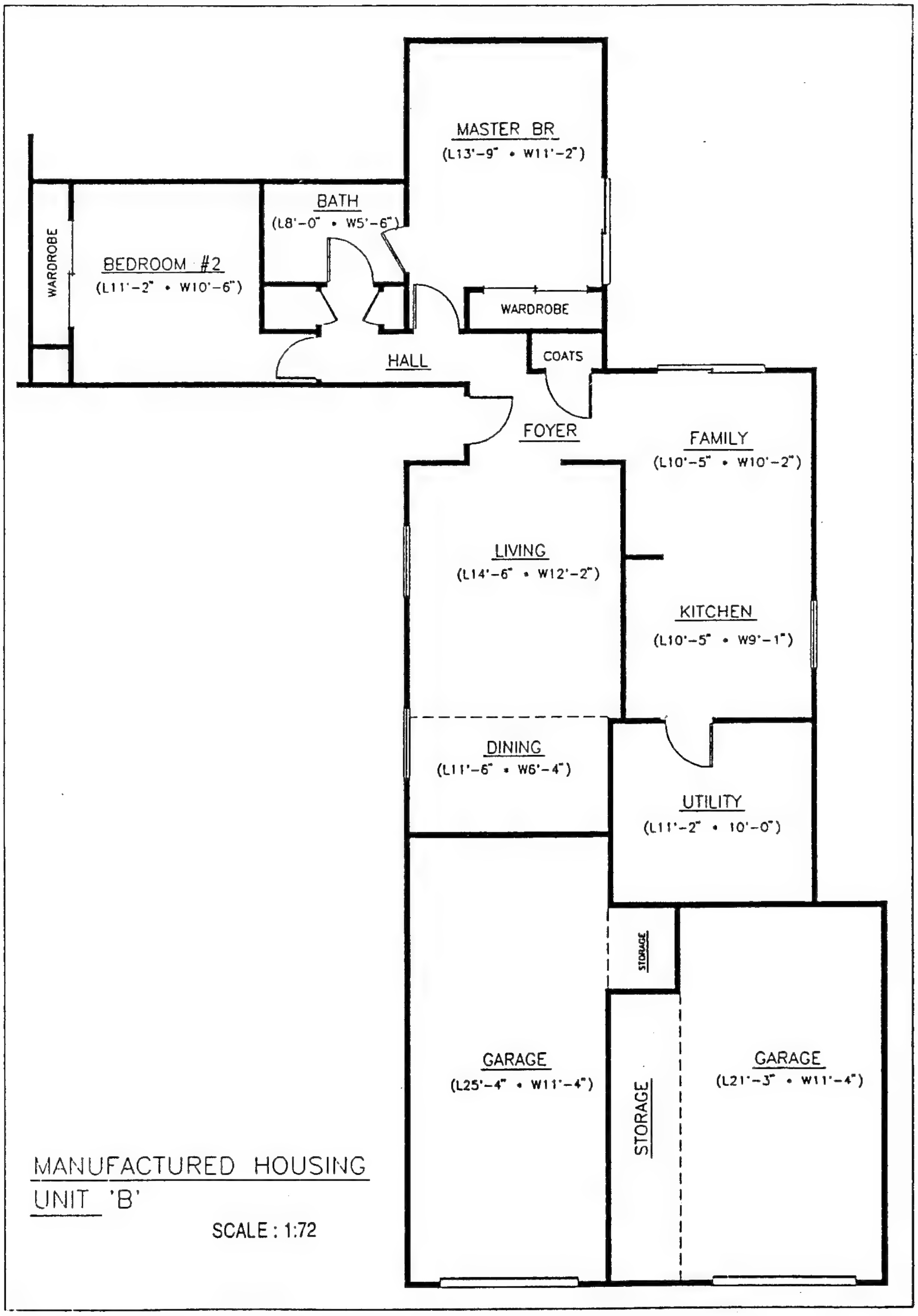


Figure A8. Floor plan for first floor MHU, Type B.

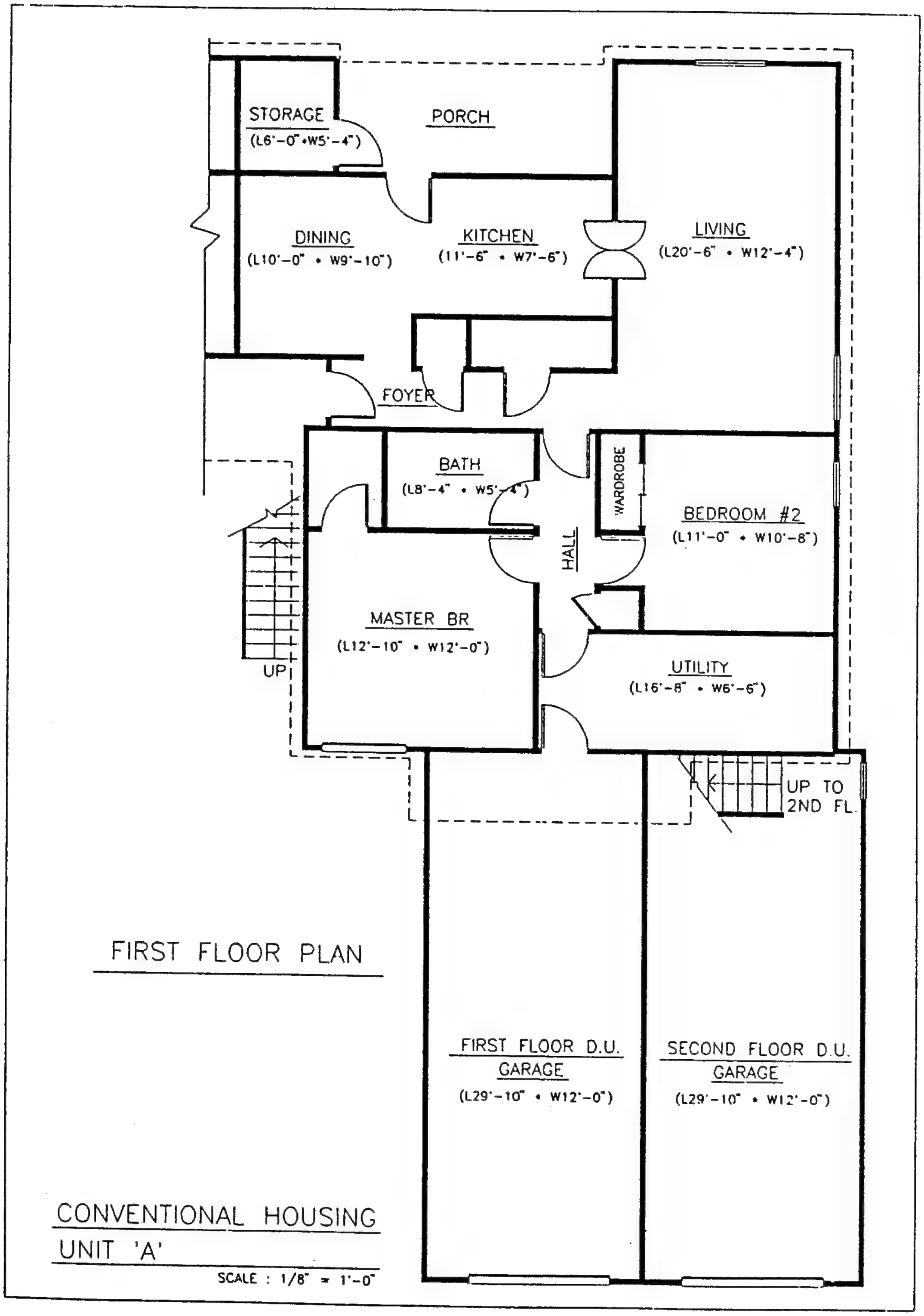


Figure A9. Floor plan for first floor CBU, Type A.

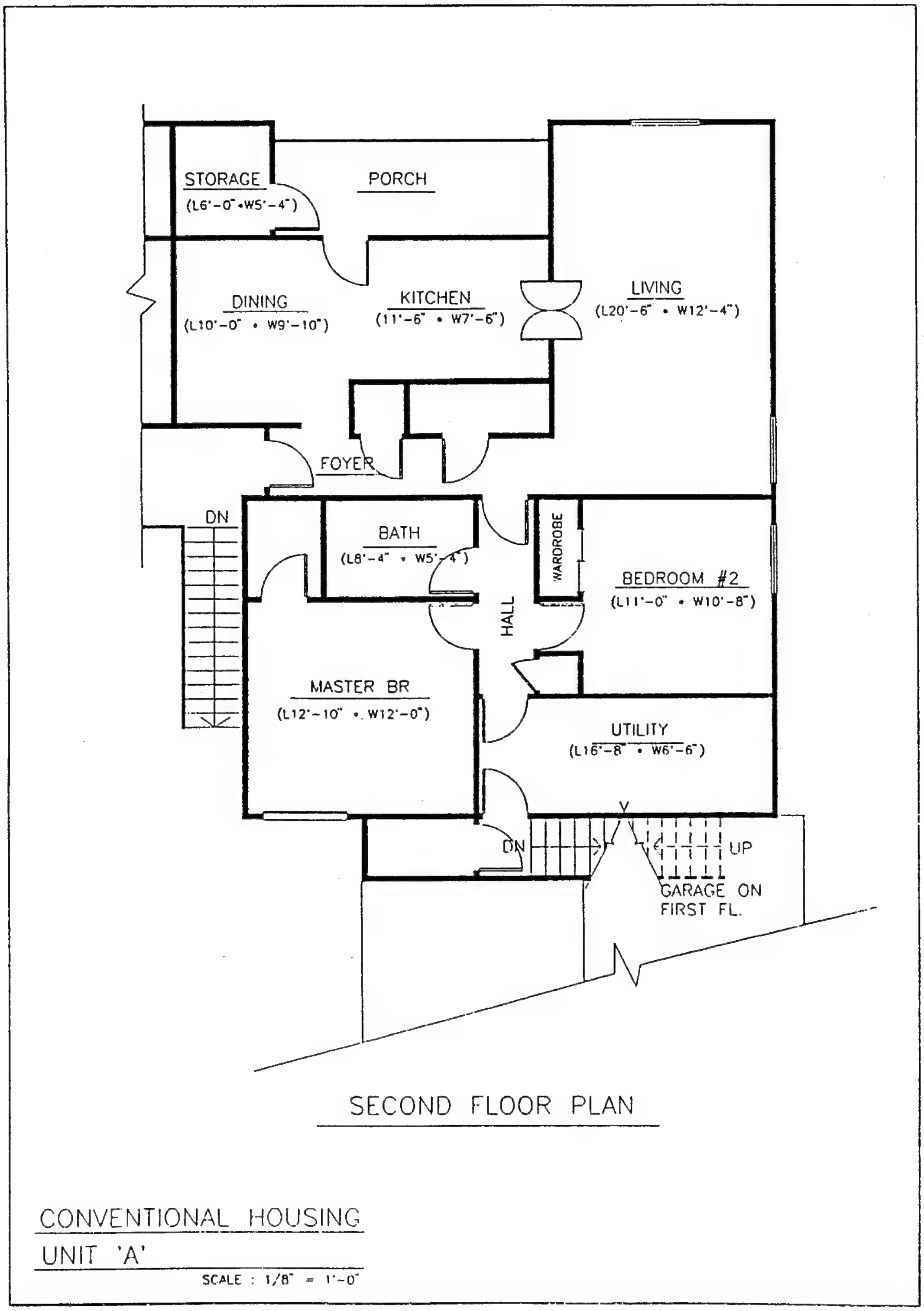


Figure A10. Floor plan for second floor CBU, Type A.

APPENDIX B: **List of Housing Units**

Conventionally Built

3680 A-F	3705 A-E	3727 A-E
3681 A-D	3712 A-F	3731 A-D
3684 A-D	3715 A-F	3732 A-F
3685 A-F	3720 A-F	3738 A-F
3690 A-F	3721 A-E	3742 A-D
3691 A-D	3722 A-E	3743 A-F
3693 A-F	3723 A-E	3745 A-F
3694 A-D	3724 A-D	3747 A-D
3695 A-D	3725 A-E	3750 A-F
3700 A-F		

Manufactured (Each with four apartments, A-D)

3800	3821	3841
3801	3822	3842
3802	3823	3843
3803	3824	3844
3804	3825	3845
3805	3826	3846
3806	3827	3848
3807	3828	3850
3809	3829	3851
3811	3831	3852
3812	3832	3853
3813	3833	3854
3814	3834	3855
3815	3835	3856
3816	3837	3857
3818	3839	3858
3820	3840	

APPENDIX C: Building Component/Subcomponent Codes

01 Roofing

0101	Roofing surface
0102	Fasteners
0103	Flashing, vents, protrusions
0104	Gutter and downspouts
0105	Other roof repairs

02 Structure

0201	Foundation and anchorage
0202	Structure, incl. framing and sheathing, stairs, cracked wall
0203	Insulation and moisture protection
0204	Masonry
0205	Exterior siding, incl. skirting
0206	Exterior doors and frames, incl. hardware and weatherstripping
0207	Storm and screen doors
0208	Window and frames, incl. hardware and weatherstripping
0209	Storm windows and screens
0210	Exterior trim
0211	Porch/deck construction
0212	Interior drywall, incl. fasteners and accessories
0213	Wall coverings and paneling
0214	Interior doors, frames, and hardware, incl. bifold and sliding
0215	Interior casework and finish carpentry
0216	Bathroom accessories, mirror
0217	Kitchen accessories, cabinets
0218	Drapery hardware
0219	Other exterior/interior repair, venetian blinds
0220	Garage door

03 Floor Coverings

0301	Resilient flooring
0302	Carpet and pad
0303	Ceramic flooring
0304	Underlayment/substrate
0305	Other flooring repairs

04 Interior Painting

0401	Walls and ceilings, incl. patching
0402	Trim
0403	Touch-up
0404	Bathtub/shower unit caulking
0405	Other Interior painting

05 Exterior Painting

0501	Walls, siding, incl. skirting
0502	Doors, frames, trim
0503	Exterior trim, incl. window, fascia, rake, soffit, etc.
0504	Caulking and sealing
0505	Glazing
0506	Other exterior painting

06 Heating

0601	Heating plant, valve
0602	Motors, blowers, pumps, G-60
0603	Ducts
0604	Piping
0605	Diffusers, grills
0606	Insulation
0607	Heating controls
0608	Other heating repairs, instructions for thermostat, turn on gas

07 Air Conditioning

0701	Cooling coils, compressor, condenser, valve, contactor
0702	Motors, blowers, pumps, transformer, fuses
0703	Piping, ducting
0704	Refrigerant
0705	Insulation
0706	Controls, delay module, relay
0707	Other cooling repairs, instruct thermostat use, filter

08 Plumbing

0801	Water heater
0802	Water softener
0803	Piping, supply, incl. valves, arrestors
0804	Faucets and shower heads
0805	Lavatories, incl. support and fasteners, caulking
0806	Water closets (i.e., toilets and commodes), incl. support and seals, caulking
0807	Bathtub/shower unit
0809	Other plumbing repair

09 Electrical

0901	Service entrance
0902	Panel box, incl. circuit breakers
0903	Branch circuits, incl. junctions, fasteners
0904	Wall receptacles and switches
0905	Doorbells, chimes
0906	Light fixtures
0907	Vents, fans
0908	Other electrical repair

10 Equipment

1001	Disposal
1002	Dishwasher
1003	Stove, range
1004	Range hood
1005	Refrigerator
1006	Other equipment

11 Utility Plant Equipment

Not applicable

12 Utility Service

1201	Water supply
1202	Gas supply
1203	Electrical service
1204	Sanitary/sewer
1205	Other utility service

13 Miscellaneous

APPENDIX D: Energy Efficiency Tests of 15 Conventionally Built Housing Units

The objective of these tests was to provide data concerning the energy efficiency of conventionally built housing. Tests were performed to determine the airtightness of the units (a measure of the resistance to air infiltration), furnace efficiencies, and heat transfer characteristics of the building envelope.

I. Tests Performed Upon Completion of Construction

Tests were conducted over 4 days in June 1983 on three types of buildings: a fourplex, a fiveplex, and a sixplex. Weather conditions were typical of the high desert area: light to negligible winds, clear skies, low humidity, and temperatures ranging from lows near 70 °F to highs near 110 °F.

House Tightness

A blower door apparatus was used to measure each unit's tightness. The blower door consisted of a variable speed fan, a digital tachometer to measure the fan blade rotation speed, and an inclined manometer to measure pressure differences. The fan could be operated to induce a positive or negative pressure difference in the house with respect to the outdoors.

To perform this test, the fan was fitted tightly into an outside door frame. A barbed fitting that penetrates the blower door was fitted with rubber tubing and connected to one side of the manometer. The other side of the manometer was open to the house. When the fan was operated, it could either force air into the house (pressurized) or force air out of the house (depressurized) depending on the direction of rotation. In either case, the pressure difference between the house and the outdoors could be read on the manometer. The fan speed was adjusted until a specified pressure difference existed (usually 0.1 or 0.2 in. of water). The fan speed required to achieve a given pressure was correlated to air flow, which indicated how tightly the house was sealed.

Each of the units was tested at 0.1 and 0.2 in. H_2O pressurized, and 0.2 in. H_2O depressurized. Some of the more obvious leaks (furnace room doors, dryer vents, attic doors) were then taped, and the house was again tested at 0.2 in. H_2O depressurized.

As shown in Table D1, airtightness was adequate, requiring no corrective work.

Furnace Efficiency

The furnaces in all the units were propane-fired. Tests were performed with a Fuel Efficiency Monitor (FEM), a hand-held automatic flue gas analyzer that measures the flue gas temperature, oxygen content, and ambient conditions and uses this information to calculate and display the percent efficiency of the furnace.

Each housing unit was first cooled down to allow the furnace to operate. The thermostats in the houses were of the "energy-saving" type, and included night setback and temperature limits. These were disconnected before each test so that the heating and air conditioning could be manually adjusted. The safety relief on the front of each furnace was covered so that room air would not be introduced into the flue. The furnace was then turned on, and a sample was taken of the intake air using the FEM. A 1/8-in. hole was then drilled in the flue of the furnace. After allowing a few minutes for the furnace to reach steady state, the FEM probe was inserted into the flue pipe and a sample was taken of the exhaust gas. The FEM took 2 to 3 min to calculate the furnace efficiency. Table D1 shows the furnaces' operational efficiencies.

Table D1

CBU Energy Efficiency Data After Construction

Building/Unit	UA* Btu/Hr-°F	No. Air Changes** Per Hour	Furnace*** Efficiency (%)
3720A	213	11.4	52.6
3720B	181	12.1	61.3
3720C	181	13.1	62.8
3720D	213	12.8	67.2
3720E	304	12.4	71.7
3720F	304	13.2	73.0
3724A	181	11.8	61.9
3724B	181	13.3	62.6
3724C	304	13.0	71.4
3724D	304	15.1	72.3
3725A	181	11.7	61.6
3725B	181	12.8	****
3725C	213	13.9	69.3
3725D	304	13.4	72.7
3725E	304	14.8	****

*These are calculated values based on the wall construction. U=heat transfer; A = area
**The following rating of air changes per hour at 0.2in. water column is based on work currently being done by Mansville Corp. for the U.S. Navy; 0 to 5, objectively tight; 5 to 10, excellent; 10 to 15, satisfactory; 15 and above merits corrective work.
***Most gas fired furnace manufacturers claim 80 percent efficiency.
****Unable to test furnace due to lack of access to the units.

Wall Heat Transfer Characteristics

A Thermo Flow Energy Meter (TEM) was obtained to test the heat transfer characteristics of the walls. The TEM is an infrared radiometer that displays heat flow digitally in units of Btu/hr/sq ft. It can be used to detect insulation defects and to estimate the thermal resistance of exterior walls.

Due to unfavorable weather, the TEM could not be used to calculate R-values. The device was also useful for detecting insulation voids. No insulation voids were found.

II. Tests Performed after 5 Years' Occupancy

The house tightness and furnace efficiency tests were performed again in May 1988. Results are summarized below in Table D2. Again, no wall insulation tests were performed because of weather conditions.

Table D2

CBU Energy Efficiency Data 5 Years After Construction

Unit No.	No. Air Changes Per Hour	Furnace Efficiency (%)
3720A	11.0	58.5
3720B	11.4	68.6
3720C	12.9	65.8
3720D	10.2	70.6
3720E	10.6	74.2
3720F	10.8	59.5
3724A	10.6	68.9
3724B	11.6	57.8
3724C	14.4	67.4
3724D	12.3	70.4
3725A	11.3	66.0
3725B	11.8	24.1
3725C	14.4	68.8
3725D	16.2	67.3
3725E	12.4	74.5

APPENDIX E: Energy Efficiency Tests of 16 Manufactured Housing Units

The objective of these tests was to provide data on the energy efficiency of manufactured housing units for comparison to existing energy efficiency data taken on conventionally built housing units. Tests were performed to determine the airtightness of the units (a measure of the resistance to air infiltration), furnace efficiencies, and heat transfer characteristics of the building envelope.

I. Tests Performed Upon Completion of Construction

Tests were conducted on three types of fourplexes; Type I (Building 3809), II (Building 3802), and IV (Buildings 3800 and 3806). The tests were conducted over 4 days in April 1984. The weather during the testing was mild for high desert area; medium to strong winds, overcast skies, low humidity, and temperatures ranging from morning lows of 40 °F to highs near 80 °F.

House Tightness

To measure the tightness of each housing unit a blower door apparatus was used, as described in Appendix D.

Each of the manufactured housing units was tested at 0.1, 0.2, and 0.3 in. of water during pressurization and then tested at 0.1 and 0.2 in. under depressurization. Then air leaks were taped (furnace doors and kitchen vents) and the unit was retested at 0.2 in. during pressurization. During the final day the winds were gusting so high that no consistent manometer reading could be taken, so Building 3809 had no data for air infiltration.

The results of the USACERL testing, as presented in Table E1, demonstrate that the airtightness of all the units except one is acceptable. Unit 3800-C had a significantly higher value than the other units and should have corrective work done to improve its tightness.

During the airtightness testing, several leaks were found. In Type II, Unit 3802-C, serious leaks were found in the door to the furnace room. In Type IV, Units 3800 and 3806, leaks were found while depressurizing around the furnace vents and doors (Unit A in both buildings). Also, leaks were found around sliding doors (Unit 3800-C), kitchen window area (Unit 3806-D), utility outlets (Unit 3800-D), and a crack in the dining room wall (Unit 3806-D).

Furnace Efficiency

The furnaces in all of the units were propane-fired. Tests were performed using a FEM, as described in Appendix D. A carbon monoxide meter similar to the FEM was used to ensure that each furnace's burner was completely combusting its fuel and that there was no unusual concentration of carbon monoxide.

Table E1

MHU Energy Efficiency Data After Construction

Building/Unit	UA* Btu/Hr-°F	No. Air Changes Per Hour	Furnace Efficiency (%)
3800A	296	9.9	75.5
3800B	296	11.5	81.8
3800C	363	18.4	80.5
3800D	363	11.3	82.6
3802A	271	9.0	70.1
3802B	271	10.1	75.1
3802C	370	12.1	81.8
3802D	370	11.3	80.3
3806A	296	8.0	78.2
3806B	296	9.8	77.4
3806C	363	8.7	80.7
3806D	363	10.6	82.2
3809A	249	**	80.0
3809B	249	**	82.0
3809C	336	**	80.7
3809D	336	**	79.6

*These are calculated based on the wall construction. U = heat transfer coefficient; A = area.
**Unable to test airtightness due to high winds.

The testing was performed in the early morning hours so there would be a low outdoor temperature to start the furnace. The safety relief on the front of each furnace was taped over to prevent room air from entering the flue. A 1/8-in. hole was drilled into the flue near the furnace. The furnace was turned on and a sample of the ambient air was taken. The furnace was then left to reach steady state (approximately 15 min) and then the FEM probe was inserted into the hole and a sample of the exhaust gas was taken. The FEM took approximately 2 to 3 min to calculate and display the efficiency. Three samples were taken to ensure furnace steady state. The hole in the flue was then taped closed.

The furnace efficiencies are typical for the size and type of furnace installed.

Wall Heat Transfer Characteristics

A TEM, as described in Appendix D, was used to test the heat transfer characteristics of the exterior walls of each unit and to detect insulation defects.

This testing was done in the early morning hours because there must be a constant temperature difference of at least 20 °F between outdoor and indoor temperatures. First the outdoor and indoor temperatures were taken until they appeared steady. The TEM was then aimed at an interior wall and the net heat flow reading was recorded. Then the TEM was aimed at an exterior wall and the heat flow through the wall was recorded. Finally, the same measurement was made on the outside of the exterior wall (being sure that the area was shaded from sunlight). These results were used in conjunction with a standardized chart to determine the wall's thermal resistance. After these measurements were taken, the TEM was used to detect areas of high net flow readings, which indicate areas of insulation defects. There appear to be a number of insulation voids in Type I, II, and IV Units.

The UA values were calculated for the units, representing the overall heat transfer for the unit inclusive of walls, windows, doors, and roof (heat transferred from one unit to the next unit was considered negligible). The insulation voids listed in Table E2 were determined when the net heat flow varied by 10 Btu/hr-°F.

II. Tests Performed After 5 Years' Occupancy

The house tightness and furnace efficiency tests were performed again 5 years after construction. Results are given in Table E3.

Table E2

Insulation Void Locations

Building/Unit	Location of Void
3802A	Void area at upper left corner of window in front bedroom.
3802C	Void area above sliding glass door in dining room.
3802D	Void area at right electrical outlet in dining room.
3806C	Void areas in all wall-to-wall seams (corners).
3806D	Void areas in all wall-to-wall seams (corners).
3809B	Void area at upper right corner of sliding glass door in dining room.

Table E3

MHU Energy Data 5 Years After Construction

Building/Unit	No. Air Changes Per Hour	Furnace Efficiency (%)
3800A	7.8	75.9
3800B	9.4	80.2
380c0	*	76.3
3800D	10.2	72.8
3802A	9.6	71.2
3802B	10.2	80.4
3802C	10.8	79.1
3802D	*	*
3806A	8.6	79.9
3806B	10.3	77.1
3806C	11.4	79.8
3806D	12.9	76.6
3809A	7.4	78.7
3809B	7.0	73.9
3809C	10.2	79.2
3809D	10.3	78.3

DISTRIBUTION

Chief of Engineers
ATTN: CEHEC-IM-LP (2)
ATTN: CEHEC-IM-LH (2)
ATTN: CERD-L
ATTN: CECC-R
ATTN: CEMP-EC

ACSIM
ATTN: DAIM-FDP
ATTN: DAIM-FD
ATTN: SFIM-IS

CECPW
ATTN: CECPW-ZC 22060
ATTN: CECPW-F 22060
ATTN: CECPW-FB 22060
ATTN: CECPW-HM-O (30) 20314

Defense Technical Info. Center 22304
ATTN: DTIC-FAB (2)

Huntsville Division 35807
ATTN: CEHND-ED

Commander 92310
National Training Center and Fort Irwin
ATTN: DPW (2)

47
9/95